Nuclear power - basis, challenges and global status

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Nuclear Power:
Basis, Challenges and Global Status

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Aarhus 17 March 2009

Overview

Overview
Present
Situation

Fission
Reactors

Opportunities
& Challenges

Future – until
2050

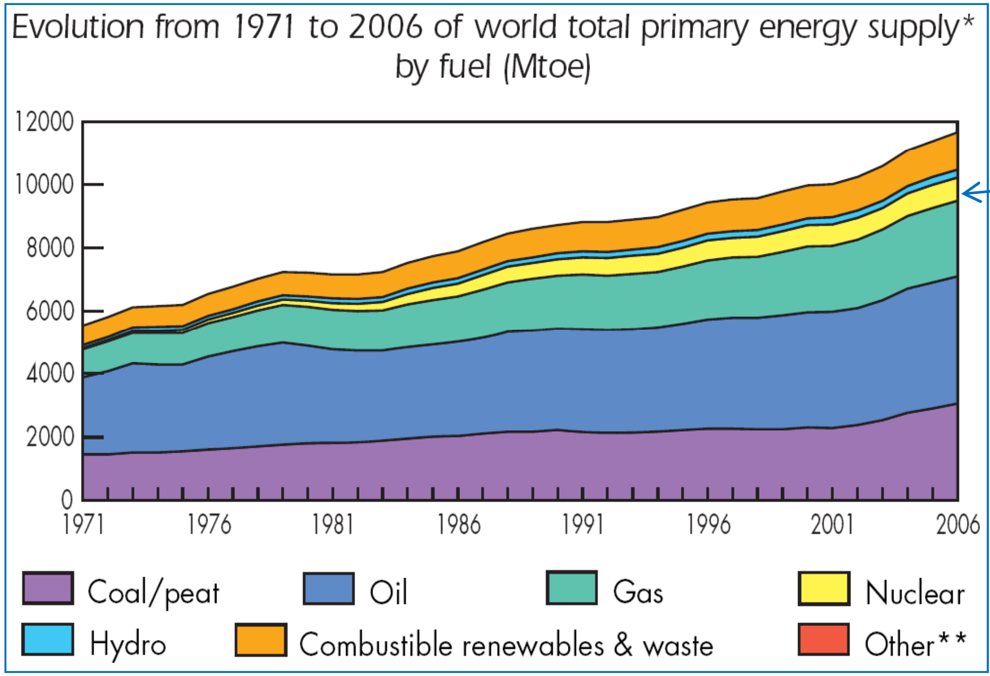
Back

Overview
Present Situation

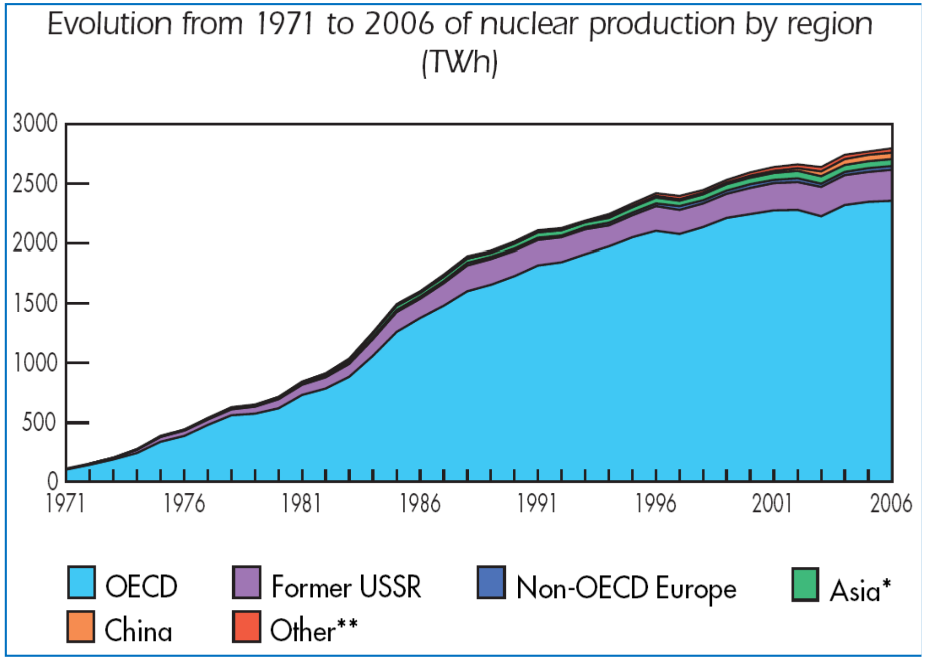
Nuclear power in brief

- 1918 Rutherford: Energy production from nuclear
- 1938 Fission
- 1942 Fermi's Reactor (natural uranium, graphite moderated thermal reactor)
- 1945 Atomic bomb
- ca. 1950 Generation I reactors: Magnox (Calder Hall)
- 1953 Atoms for peace (Dwight Eisenhower)
- ca. 1965 Generation II: PWR, BWR
- 1979 Three Mile Island
- 1985 DK: No nuclear power
- 1986 Chernobyl accident
- 1999 Barsebäck-1 closes
- 2002 Finnish newbuild
- Today Renaissance for nuclear power?

Nuclear Power in the World Today



Nuclear power provides approximately 6 % of world total primary energy supply



Most of the nuclear power production has been added during the last 35 years. Nuclear provides about 2 610 TWh per year, which is 14.2% of all electric energy production (2007).

Source: IEA Key World Energy Statistics 2008

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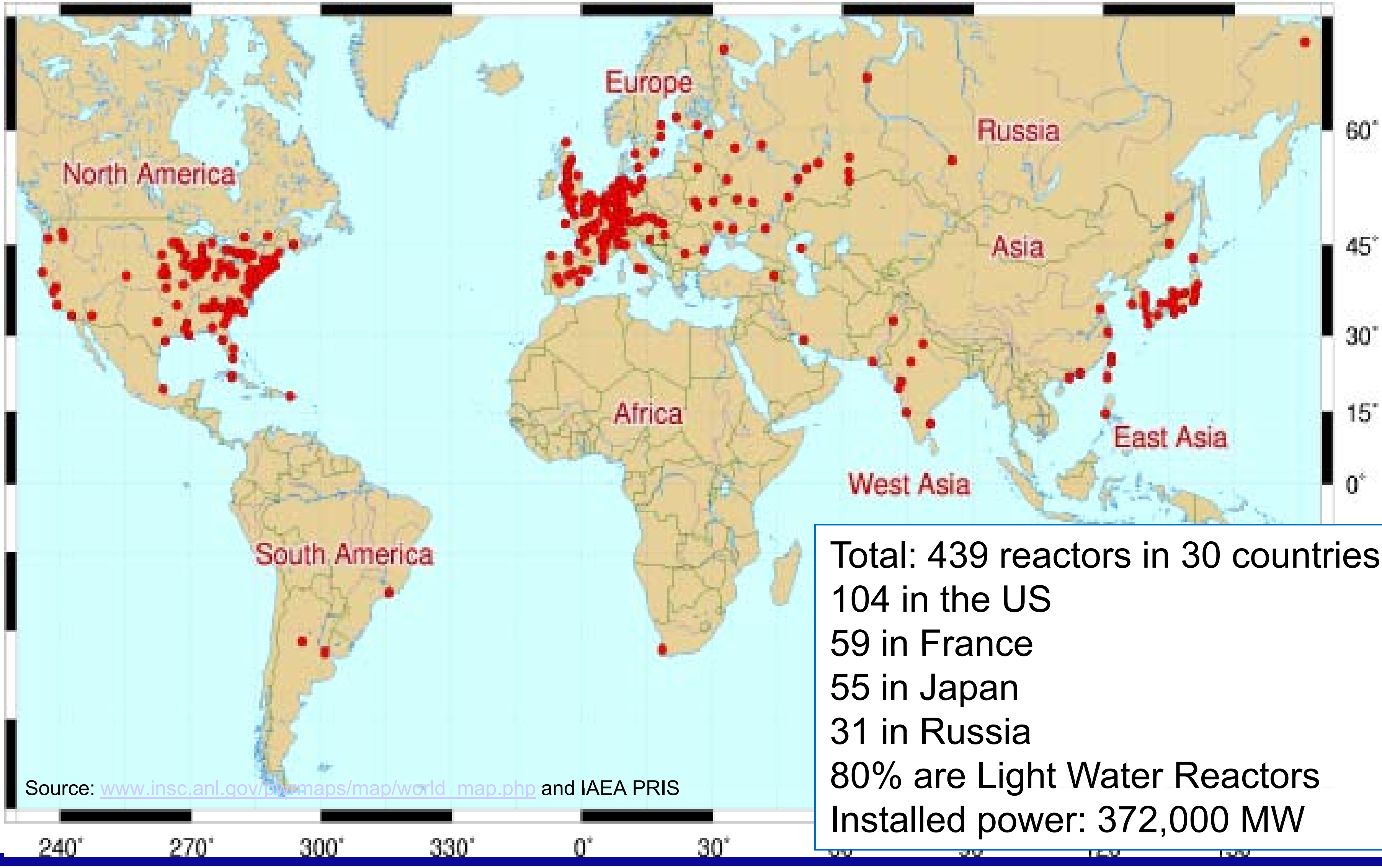
Nuclear Power Plants in the World



Source: www.insc.anl.gov/pwrmaps/map/world_map.php and IAEA PRIS

Total: 439 reactors in 30 countries
104 in the US
59 in France
55 in Japan
31 in Russia
80% are Light Water Reactors
Installed power: 372,000 MW

Nuclear Share of Electricity Generation

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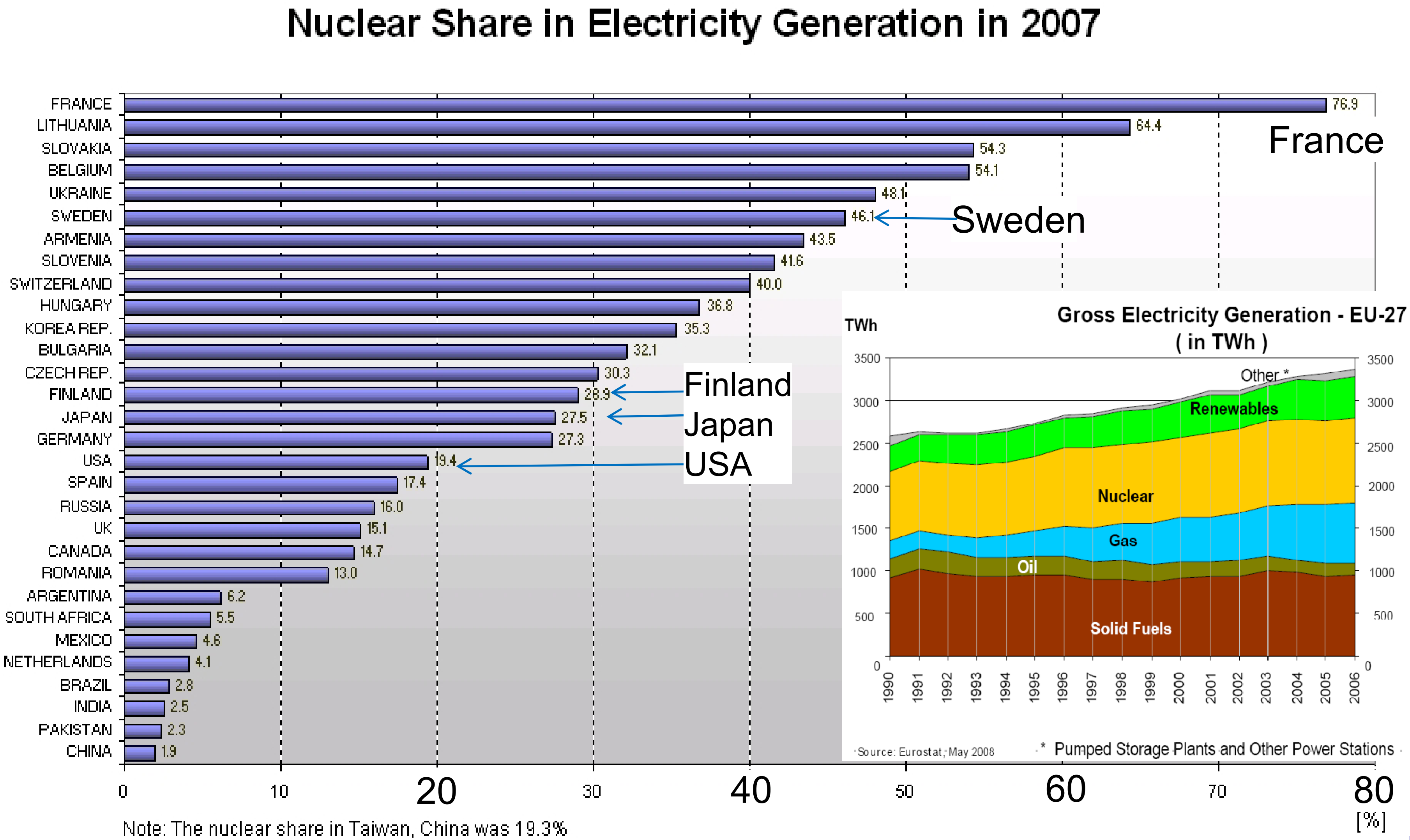

Note: The nuclear share in Taiwan, China was 19.3%

Source: IAEA PRIS

Nuclear Power Plants in Europe

- Most of the world NPPs are in Europe (198 out of 439)
- Europe has the largest installed power in NPPs (172 GW out of 372 GW in total)
- Europe produces most electric energy from NPPs (1200 TWh out of 2610 TWh in total)
- 30% of EU´s electric energy is from NPPs

För att ersätta en reaktor i Forsmark...

- Forsmark 1 och Forsmark 2 har en nettoeffekt på nära 980 megawatt vardera – det motsvarar drygt 1,3 miljoner hästkrafter.
- Forsmark 3 har en nettoeffekt på 1 170 megawatt – det motsvarar nära 1,6 miljoner hästkrafter.

Under ett års drift gör varje reaktor av med 20 ton uranbränsle, det är cirka en femtedel av den totala mängden bränsle i reaktorn. Skulle en reaktor ersättas med något alternativ krävs något av följande per år:

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För att ersätta en reaktor i Forsmark krävs

Vindkraft

I snitt lämnar ett vindkraftverk full effekt 2 000 timmar per år, då krävs ett par tusen vind-kraftverk.

Biobränsle (träflis)

16,5 miljoner m^3. Det är runt 15 procent av den totala skogs-avverkningen i Sverige.

Stenkol

Tre miljoner ton. Det är lika mycket som Sveriges årliga import.

Vattenkraft

Naturgas eller olja

- ***Naturgas:*** 2,1 miljarder m^3. Det är mer än dubbelt så mycket som Sverige importerar idag.
- ***Olja:*** 2,1 miljoner m^3. Det är en tredjedel av allt bränsle som bilarna i Sverige förbrukar.

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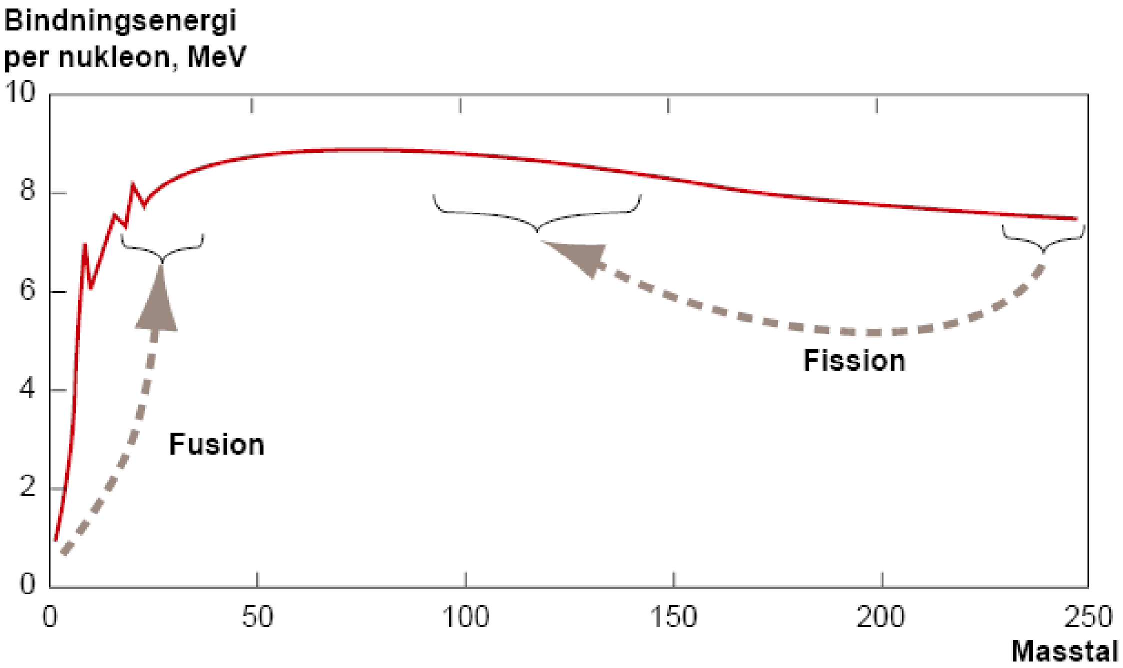
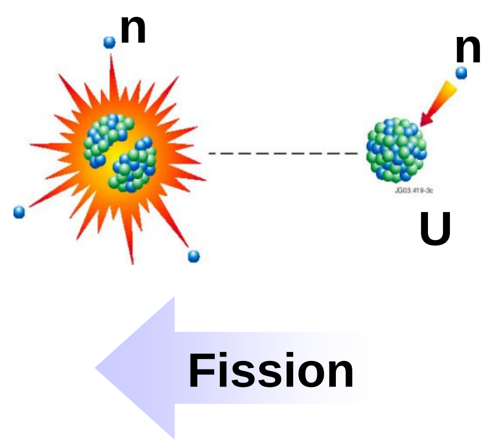
Fission reactors

Fission and fusion processes

Nuclear binding energy



Figur 1 Atomkärnornas bindningsenergi



Binding energy: $E = \Delta m \cdot c^2 = \left(Z \cdot m_p + N \cdot m_n - m_a \right) \cdot c^2$

Energy released in fission of U-235

$^{235}U + n \rightarrow {}^{144}Ba + {}^{90}Kr + 2n + 200\ \text{MeV}$

Fission energy:

$$\Delta E = E_B\left({}^{144}\text{Ba}\right) + E_B\left({}^{90}\text{Kr}\right) - E_B\left({}^{235}\text{U}\right)$$

$$\approx 144 \cdot 8.4\,\text{MeV} + 90 \cdot 8.6\,\text{MeV} - 235 \cdot 7.6\,\text{MeV}$$

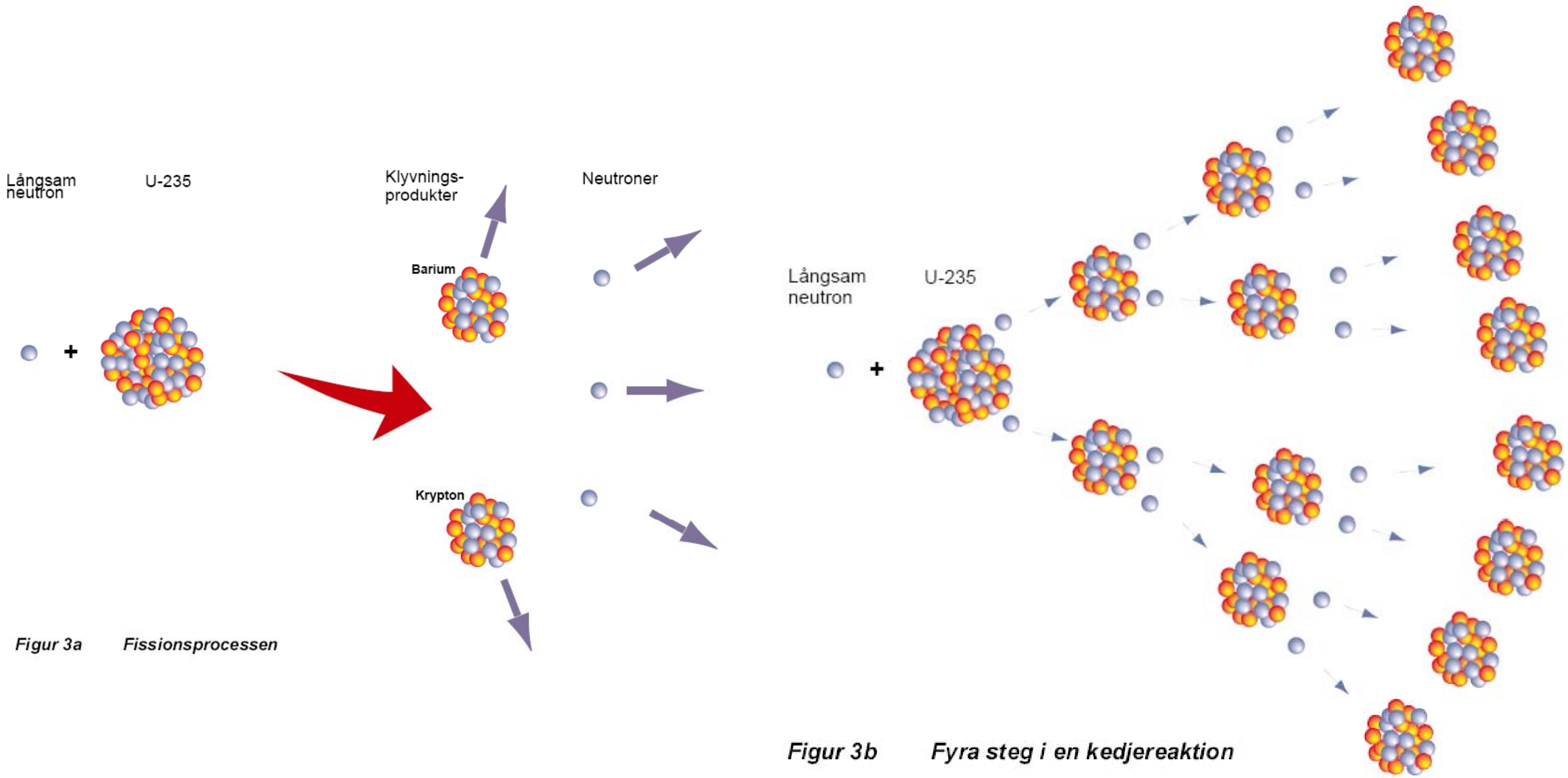
$$\approx 200\,\text{MeV}$$

Fossil fuel: $C + O_2 \rightarrow CO_2 + 4.1\ \text{eV}$

Energy released in fission

Energy	MeV
Kinetic energy of fission fragments	168
Prompt gamma radiation	5
Kinetic energy of fission neutrons	5
Beta decay of fission products	7
Gamma decay of fission products	6
Neutrinos	11
Total	202

Nuclear chain reaction



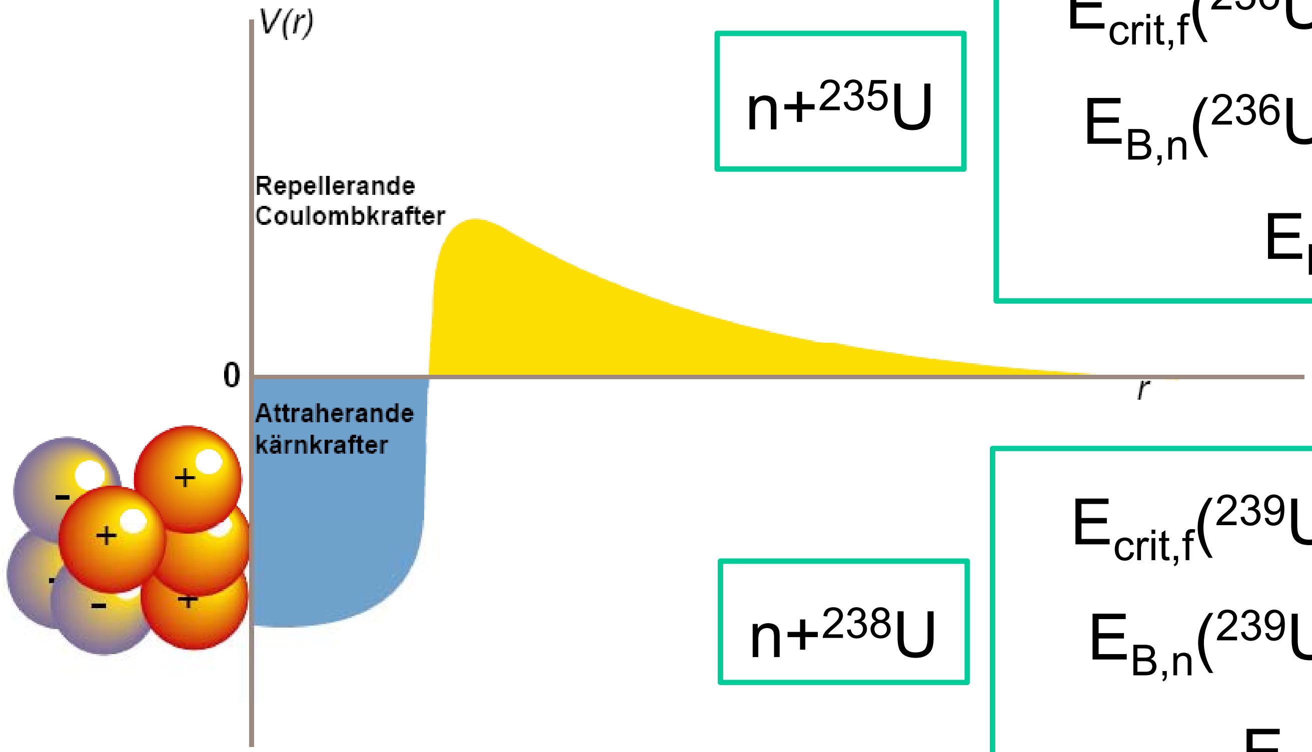
Nuclear chain reaction

- Effective multiplication factor (k_{eff}): No. fission neutrons in one generation / neutrons in previous generation
    - $k_{eff} < 1$ subcritical
    - $k_{eff} = 1$ critical
    - $k_{eff} > 1$ supercritical

- Neutron economy:
    - neutron leakage
    - non-fission cross section

Safe reactor operation: $k_{eff} < 1.001$

Nuclear and Coulomb forces



Figur 2 *Principskiss av Coulombbarriären*

$n+{}^{235}U$

$E_{crit,f}({}^{236}U) \approx 6.5$ MeV

$E_{B,n}({}^{236}U) \approx 6.8$ MeV

$E_{B,n} > E_{crit,f}$

$n+{}^{238}U$

$E_{crit,f}({}^{239}U) \approx 7.0$ MeV

$E_{B,n}({}^{239}U) \approx 5.5$ MeV

$E_{B,n} < E_{crit,f}$

Fission cross section – ^{235}U

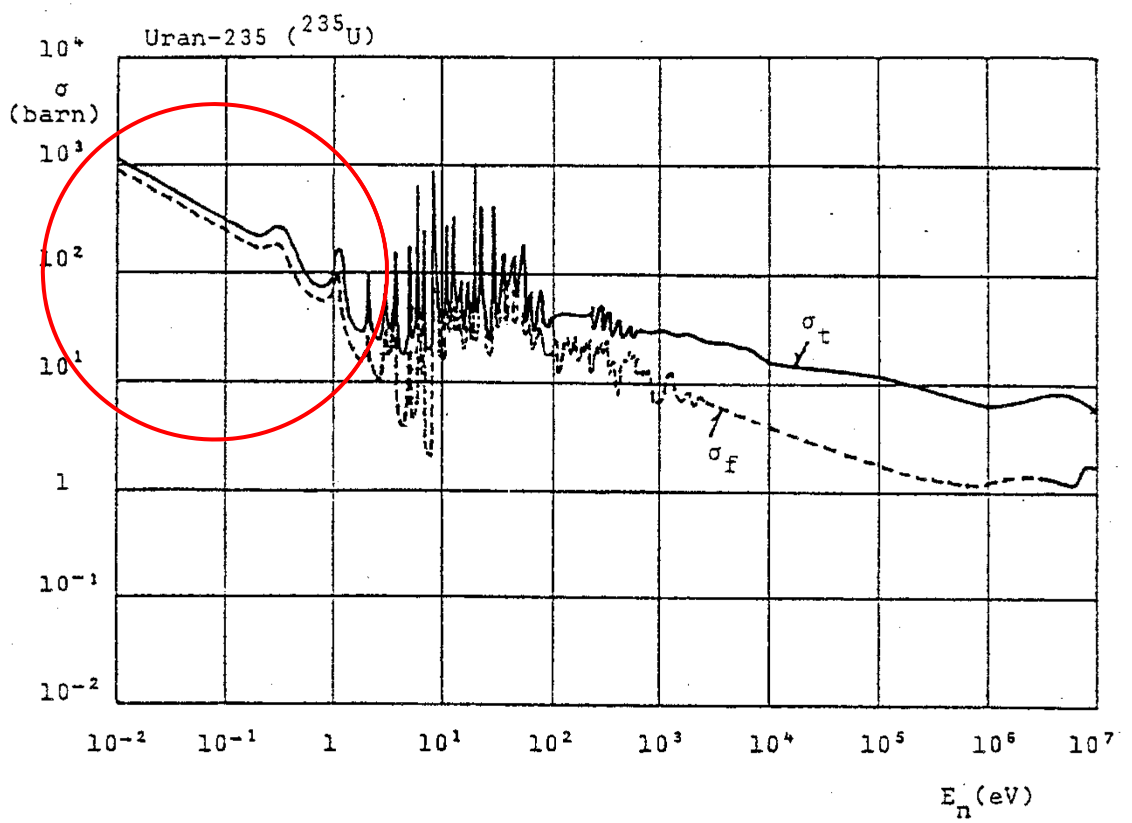


Fig.23. Uran-235's total- og fissionstværsnit versus neutronenergien.

Fission cross section – ^{238}U

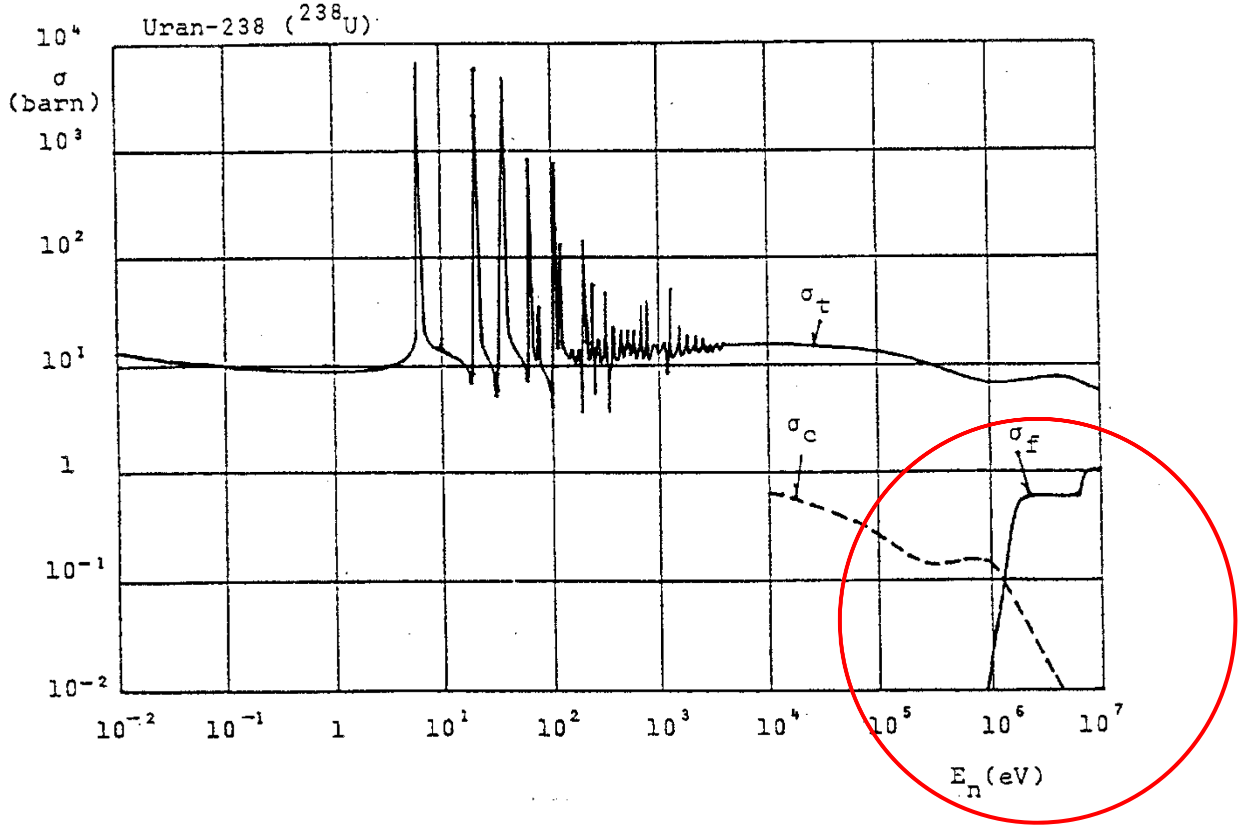


Fig.22. Uran-238's total-, fissions- og indfangningstværsnit uden fission versus neutronenergien.

Nuclear chain reaction

A self-sustained chain reaction is not possible in natural uranium (0.7% ^{235}U)

1. Fast neutrons, 10-20% enriched uranium fuel
2. Thermal neutrons, moderator: ^{12}C, H_2O, D_2O, and natural or 2-5% enriched uranium fuel

Nuclear chain reaction – thermal neutrons

- Fuel breeding:

$$n + {}^{235}U \rightarrow \text{fission fragments} + n + n + \ldots$$

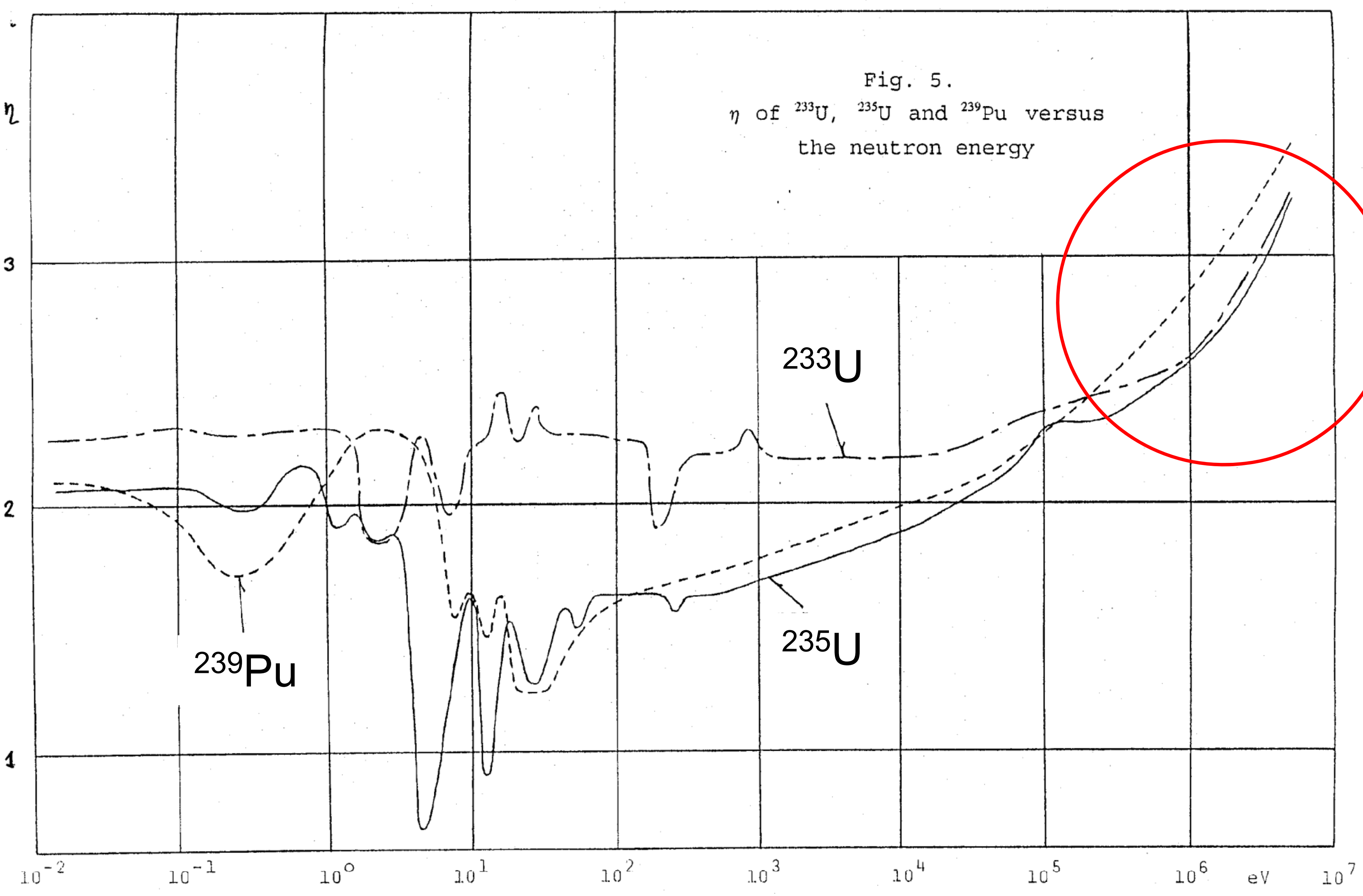
$$n + {}^{238}U \rightarrow {}^{239}U \rightarrow {}^{239}Pa \rightarrow {}^{239}Pu$$

- Neutron yield (η):
  No. produced neutrons per captured **thermal** neutron

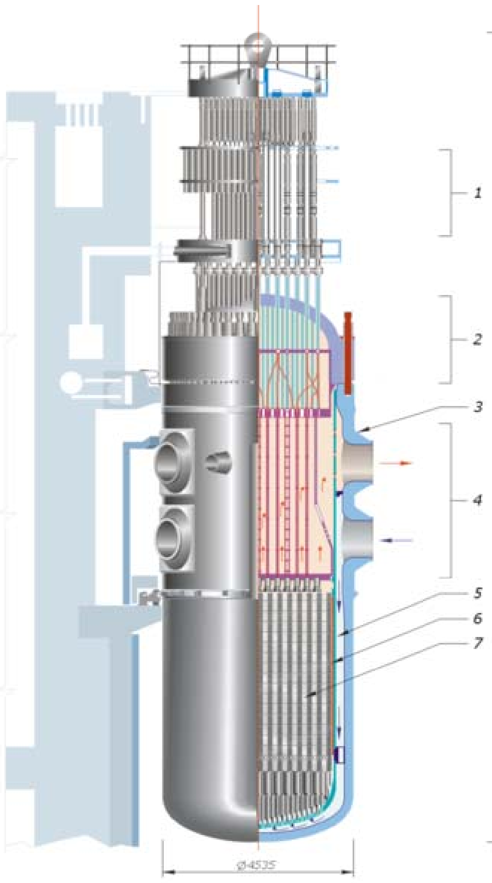
Nuclide	^{233}U	^{235}U	^{239}Pu	Nat. uran.
η	2.28	2.05	2.09	1.3

→ Fast neutrons needed for breeder reactors

η for ^{233}U, ^{235}U og ^{239}Pu

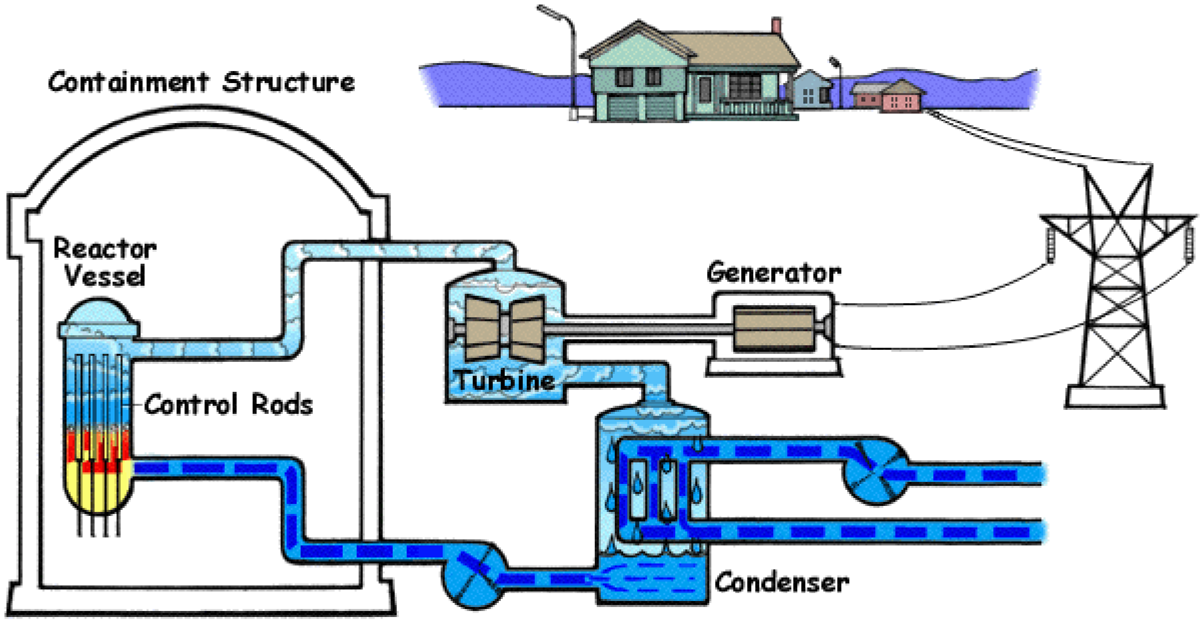


Nuclear reactors by type

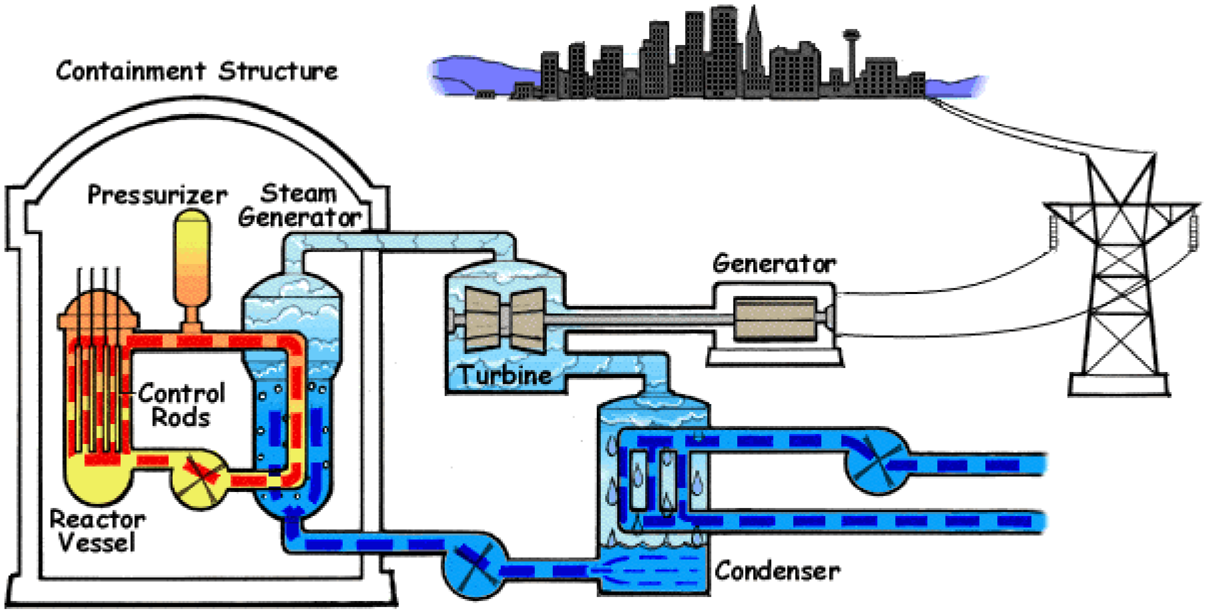


	Thermal (LWR, HWR, GCR)	Fast (FBR, LMFBR)
Fuel	3-5% U-235 Pu-239	10-20% U-235 Pu-239 Th-232 + U-233
Moderator	H_2O, D_2O Graphite	—
Coolant	H_2O, D_2O CO_2, He	Liquid metals, metal alloys

Boiling Water Reactor - BWRc



Pressurized Water Reactor - PWR



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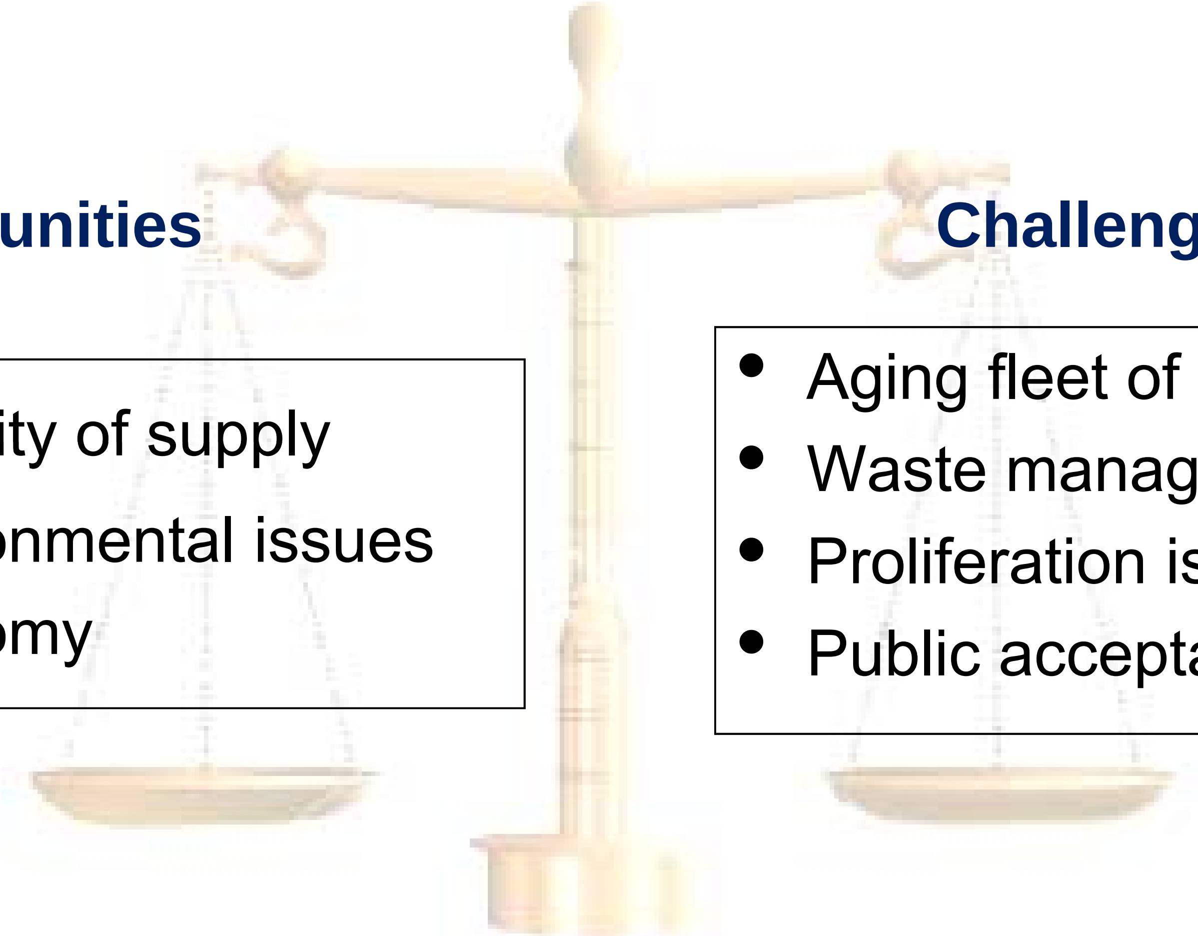
Opportunities and Challenges

Nuclear renaissance?



Opportunities

- Security of supply
- Environmental issues
- Economy

Challenges

- Aging fleet of reactors
- Waste management
- Proliferation issues
- Public acceptance

Fuel – Uranium Supply

- Uranium will last 100-200 years depending on the scenario for new builds
- Uranium will last thousands of years if reprocessing and recycling is applied
- Thorium is another reserve that can be used

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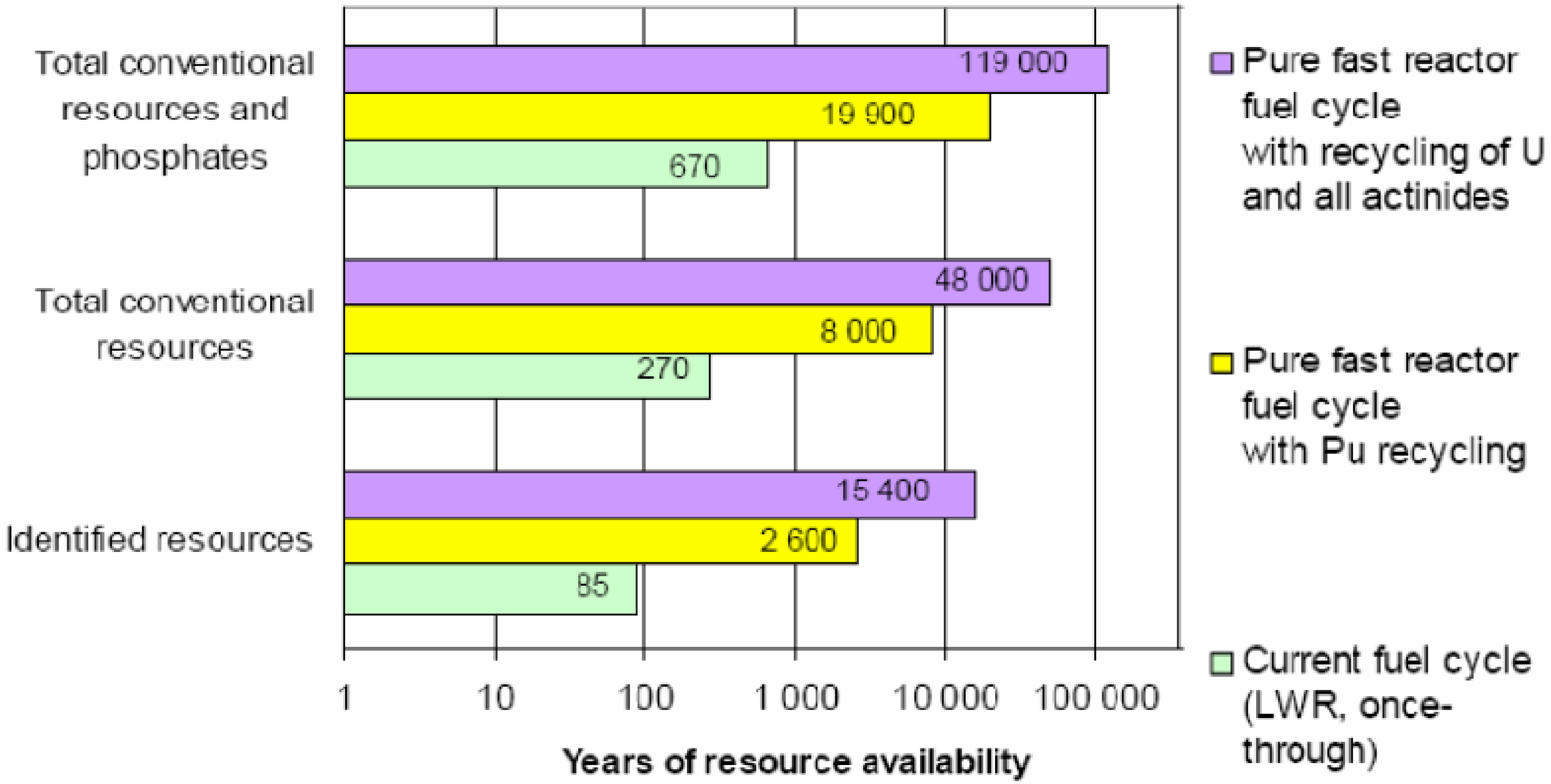
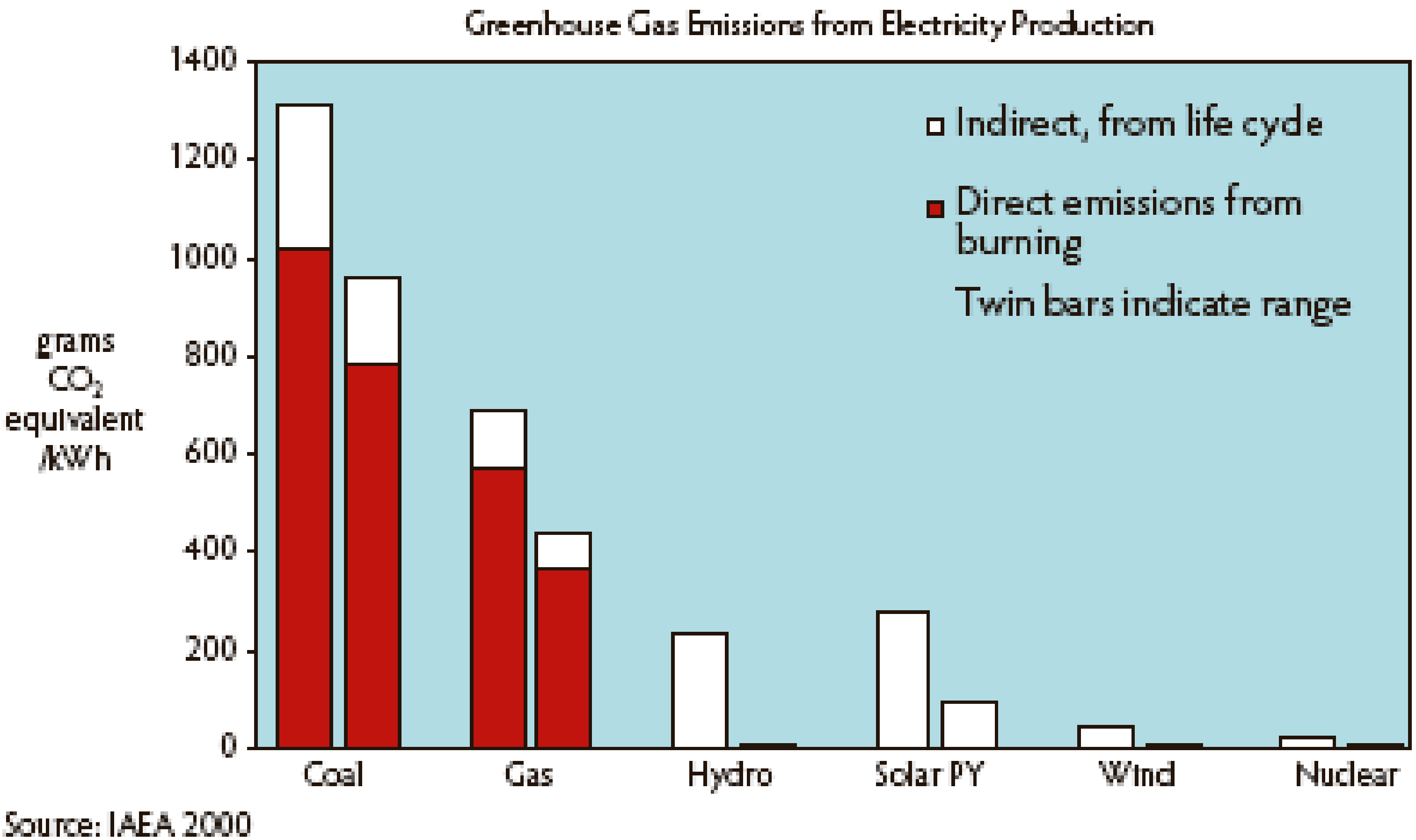


Source: *Uranium 2005 – Resources, Production and demand, Joint Report by the OECD NEA and IAEA.*

Carbon footprint



Costs of Nuclear Energy Production

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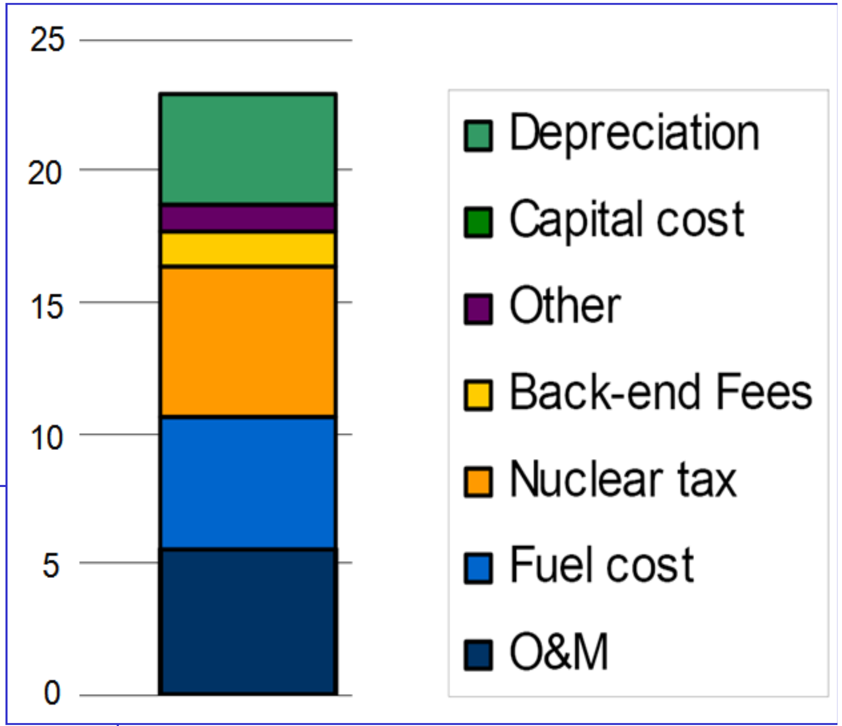
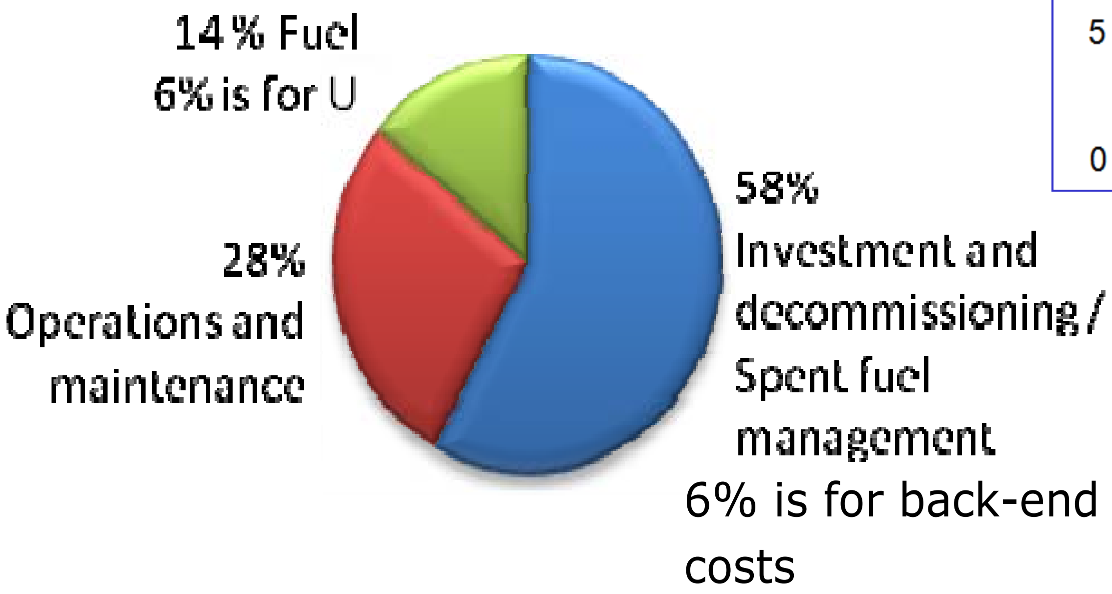
Typical Swedish Cost Distribution (öre/kWh)



Typical International Cost Distribution



Costs of Nuclear Energy Production

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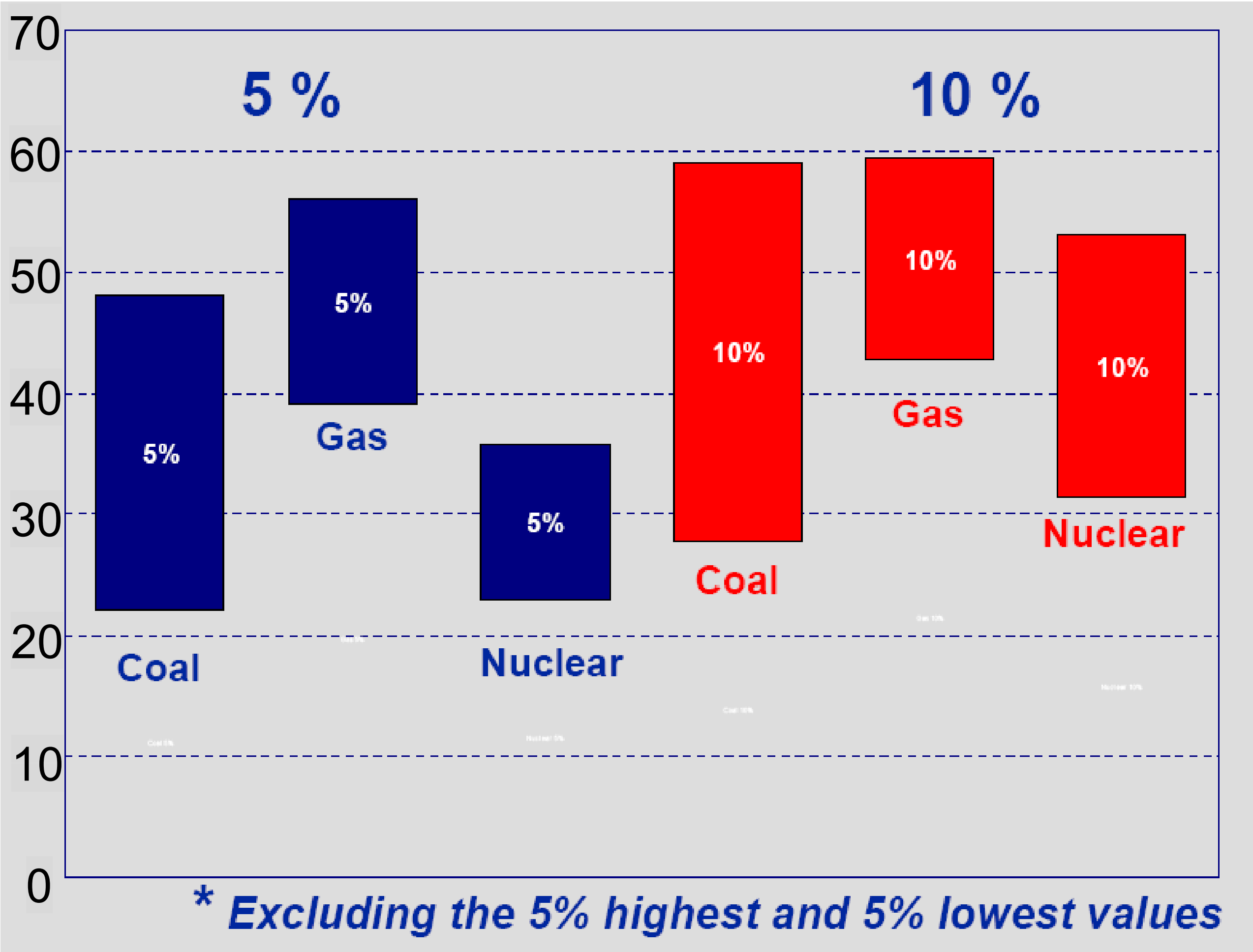
Levelised Cost (USD/MWh)

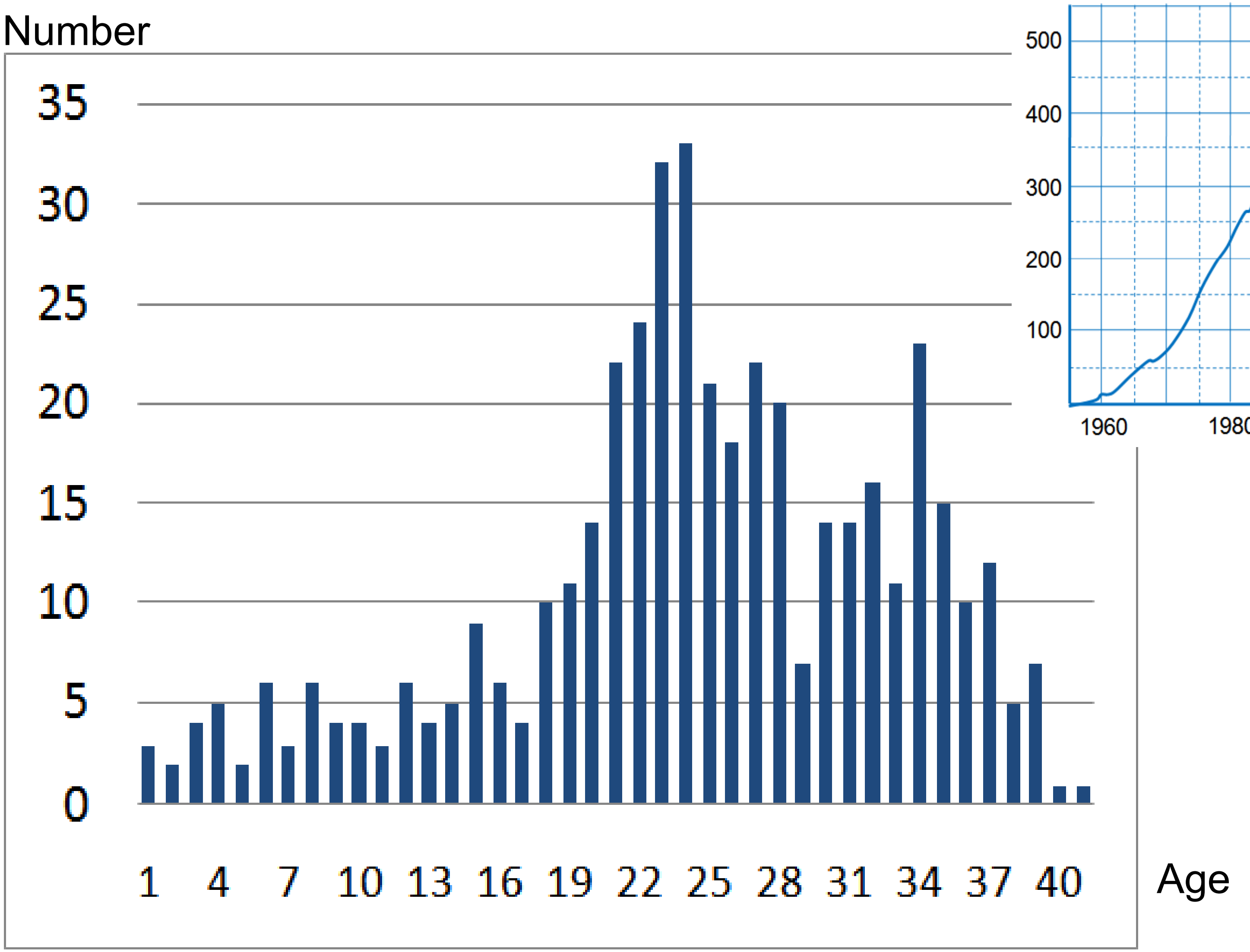


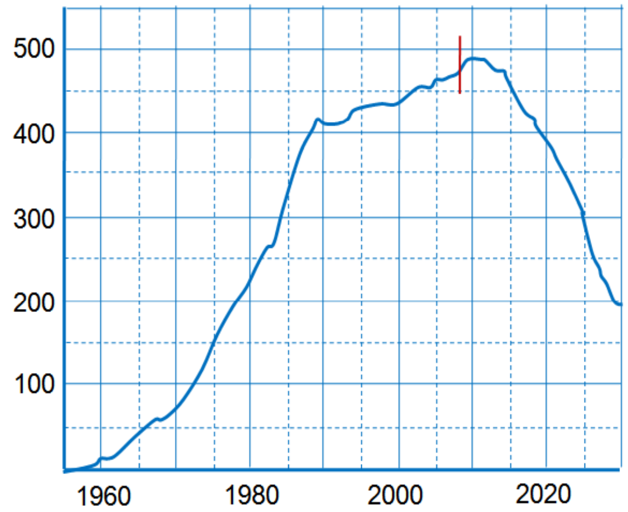
Source: OECD/NEA, IEA study 2005

Challenges for nuclear power production

Main challenges
Aging fleet of reactors
Waste management
Proliferation issues
Public acceptance

An Aging Fleet of Reactors





Source: IAEA PRIS

Life Extension is Required

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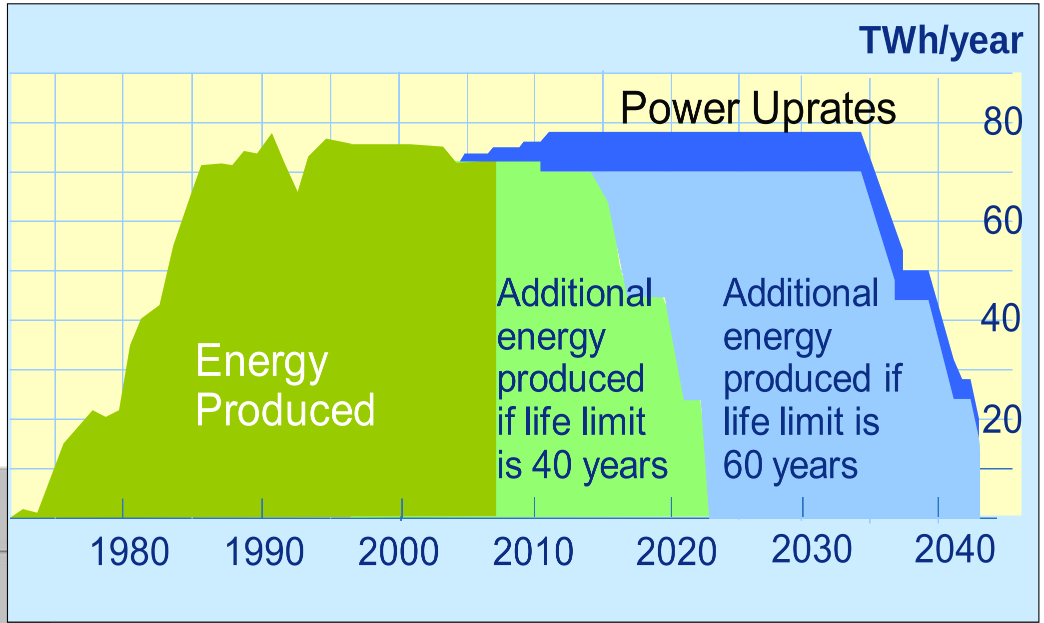
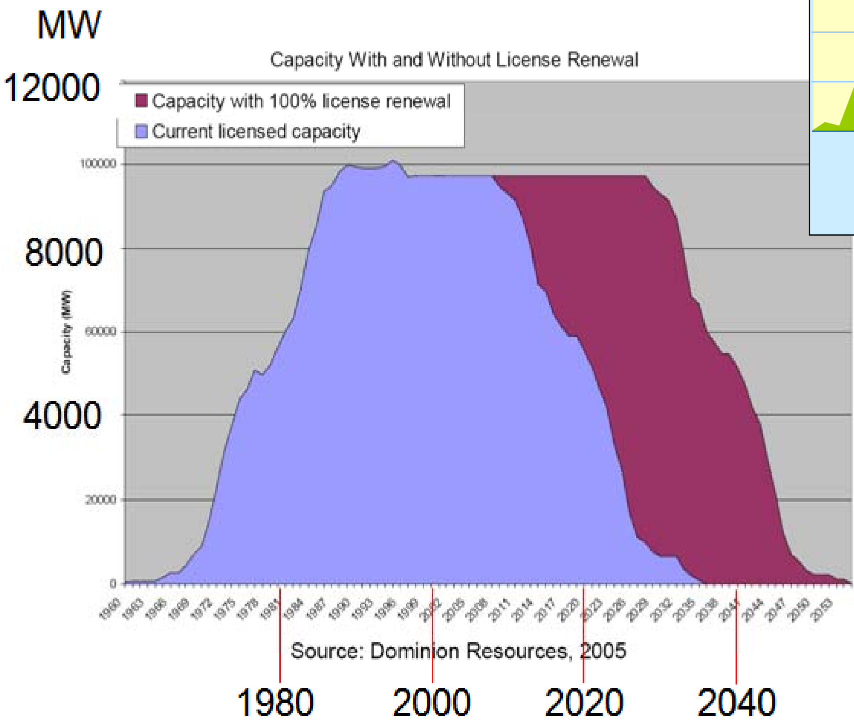
SWEDEN

Original design life-time typically 40 years.
Most owners aim for an extension to 60 years.





USA

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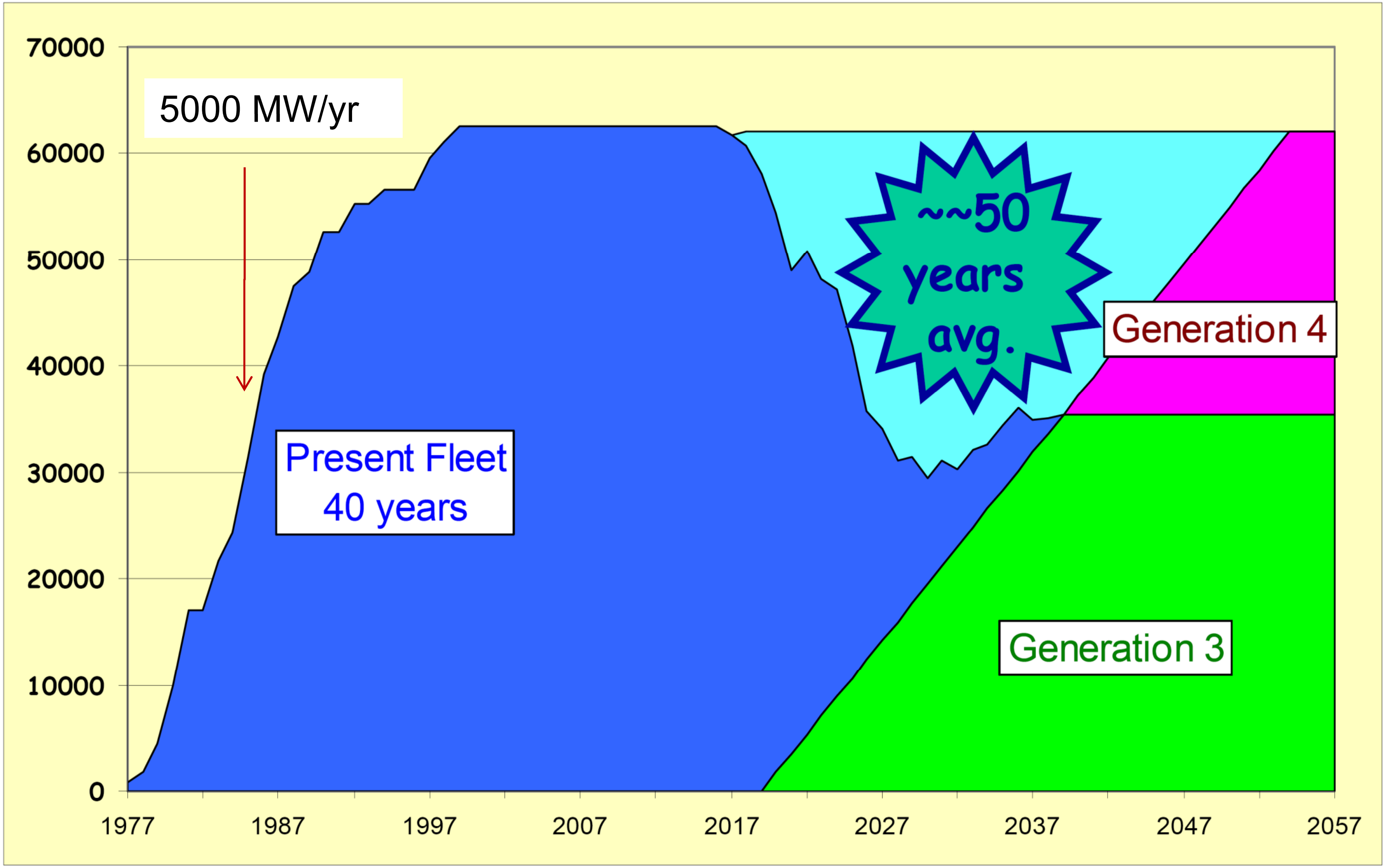
Life-Extension and New Technology are Required, France



Source: EDF at ICAPP ´07

Waste Handling and Storage

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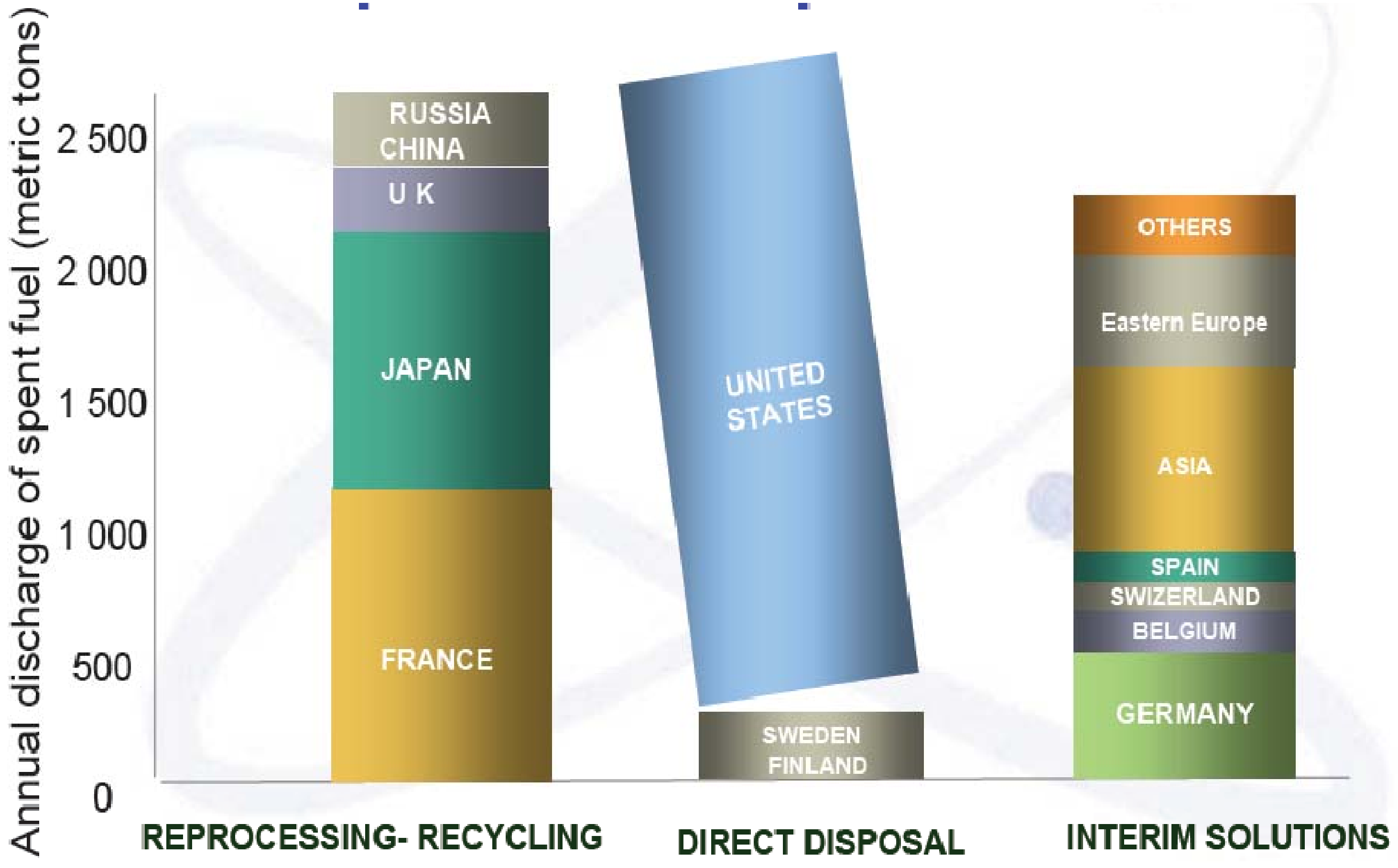
- Waste handling approach varies between countries – reprocessing requires large scale investments



Reprocessing and Re-cycling to Reduce Radiotoxicity

- Radiotoxicity – relative to natural uranium

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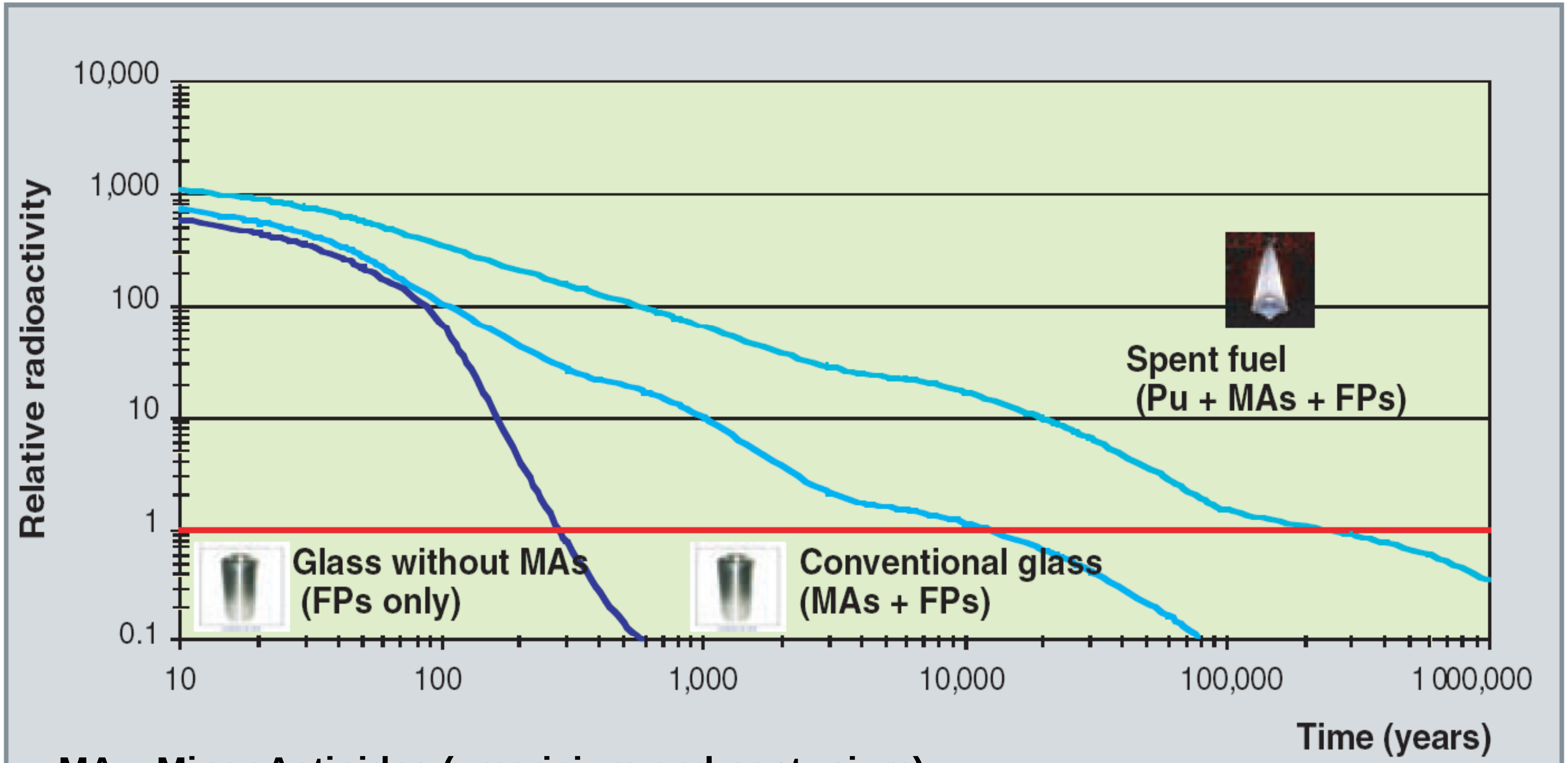


MA = Minor Actinides (americium and neptunium)
FP = Fission Products

Public & Political Acceptance

Eurobarometer QA1 (2007)

When you think about nuclear power, what comes first to mind:

A The advantages of nuclear power as an energy source outweigh the risks it poses

B The risks of nuclear power as an energy source outweigh its advantages

Eurobarometer QA1

When you think about nuclear power, what comes first to mind:

A The advantages of nuclear power as an energy source outweigh the risks it poses

B The risks of nuclear power as an energy source outweigh its advantages

DK:	A: 28%, B: 66%, neither: 6%
EU:	A: 33%, B: 53%, neither: 14%

Eurobarometer QA5 (2007)

How well informed do you think you are about the safety of nuclear power plants?

- Very well informed
- Fairly well informed
- Not very well informed
- Not at all informed

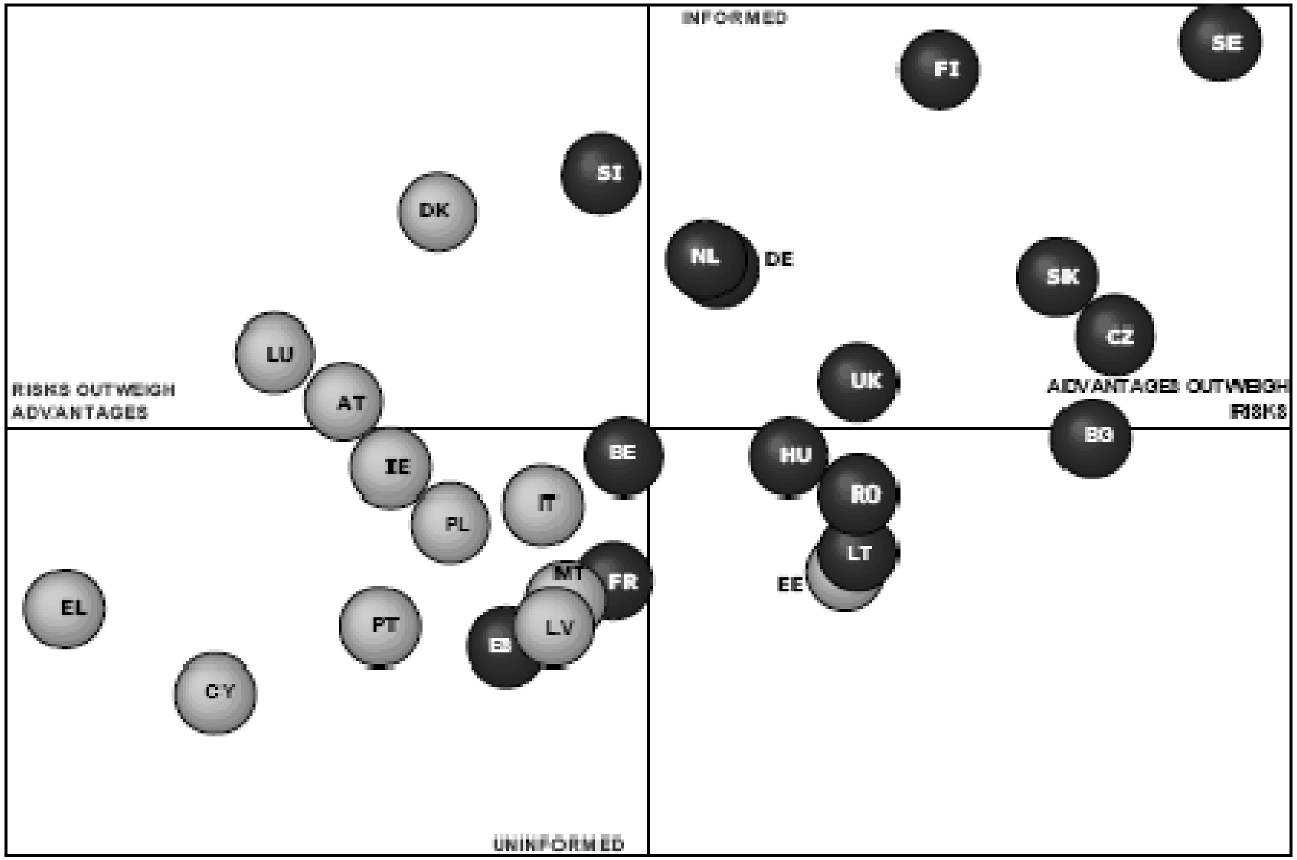
Eurobarometer QA5

How well informed do you think you are about the safety of nuclear power plants?

- Very well informed
- Fairly well informed
- Not very well informed
- Not at all informed

	DK	EU
• Very well or well informed	34%	23%
• Not very well or not at all informed	64%	76%
• Neither	2%	1%

POSITION OF EUROPEAN COUNTRIES ACCORDING TO RISK PERCEPTION AND THE FEELING OF BEING INFORMED



Feeling of beeing informed vs. risk perception

Public Acceptance and Political Decisions

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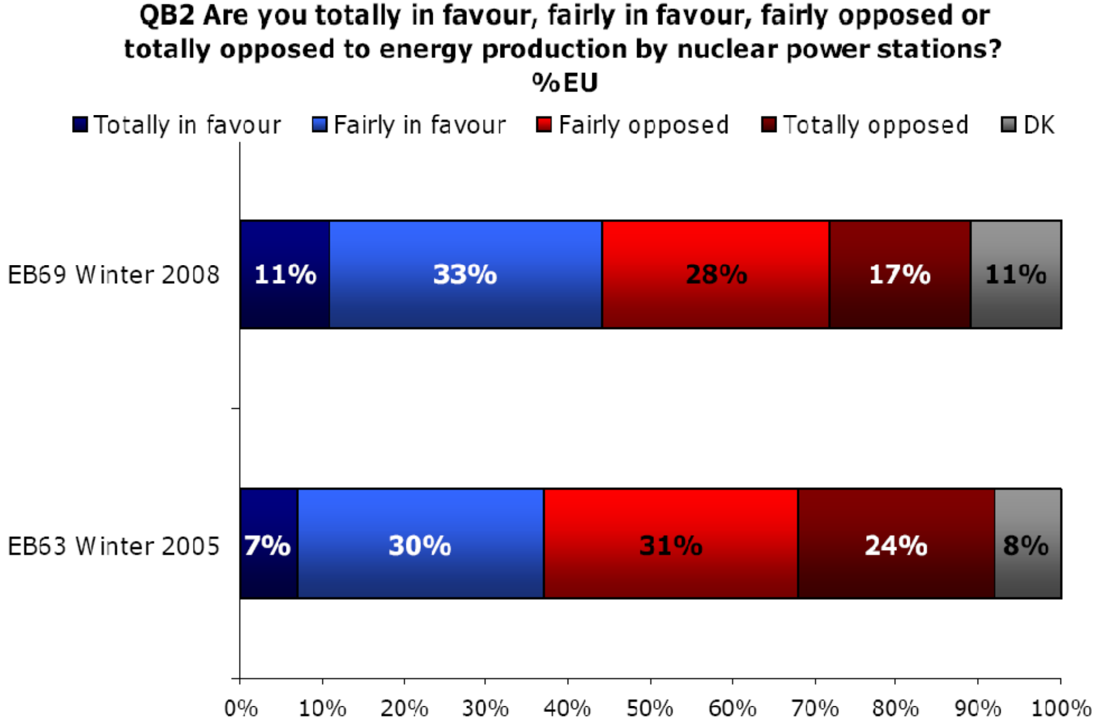
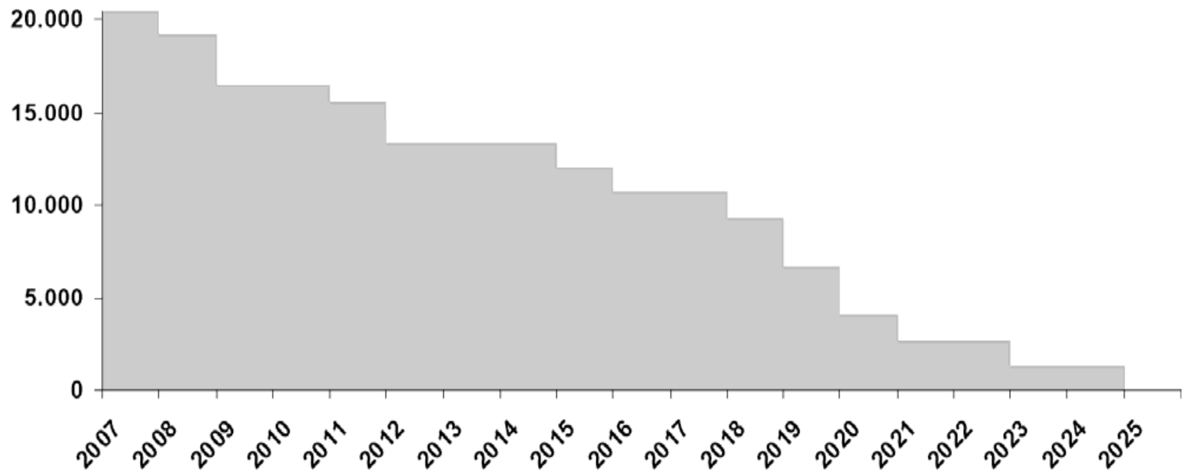


Public Opinion Development

Political Decision to build 10-15 GW New Nuclear Power in the UK confirmed January 2008

Political Decision for Nuclear Phase-out in Germany

Source: Special Eurobarometer 297. "Attitudes towards Radioactive Waste", June 2008



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The Future

Until 2050 and beyond

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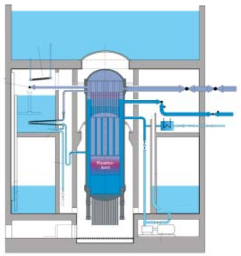
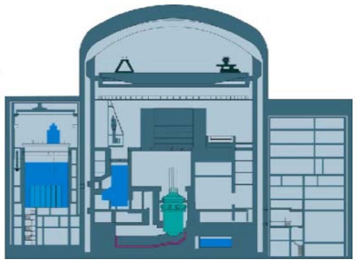
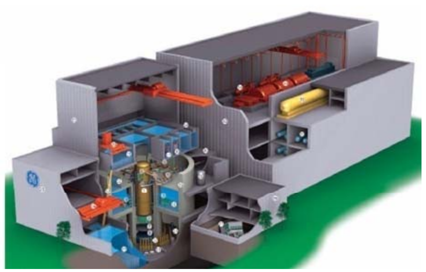
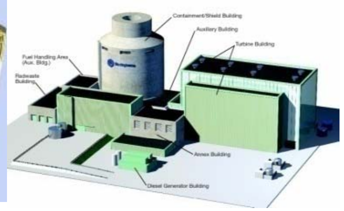
Generation 3 och 3+
Available on the market today

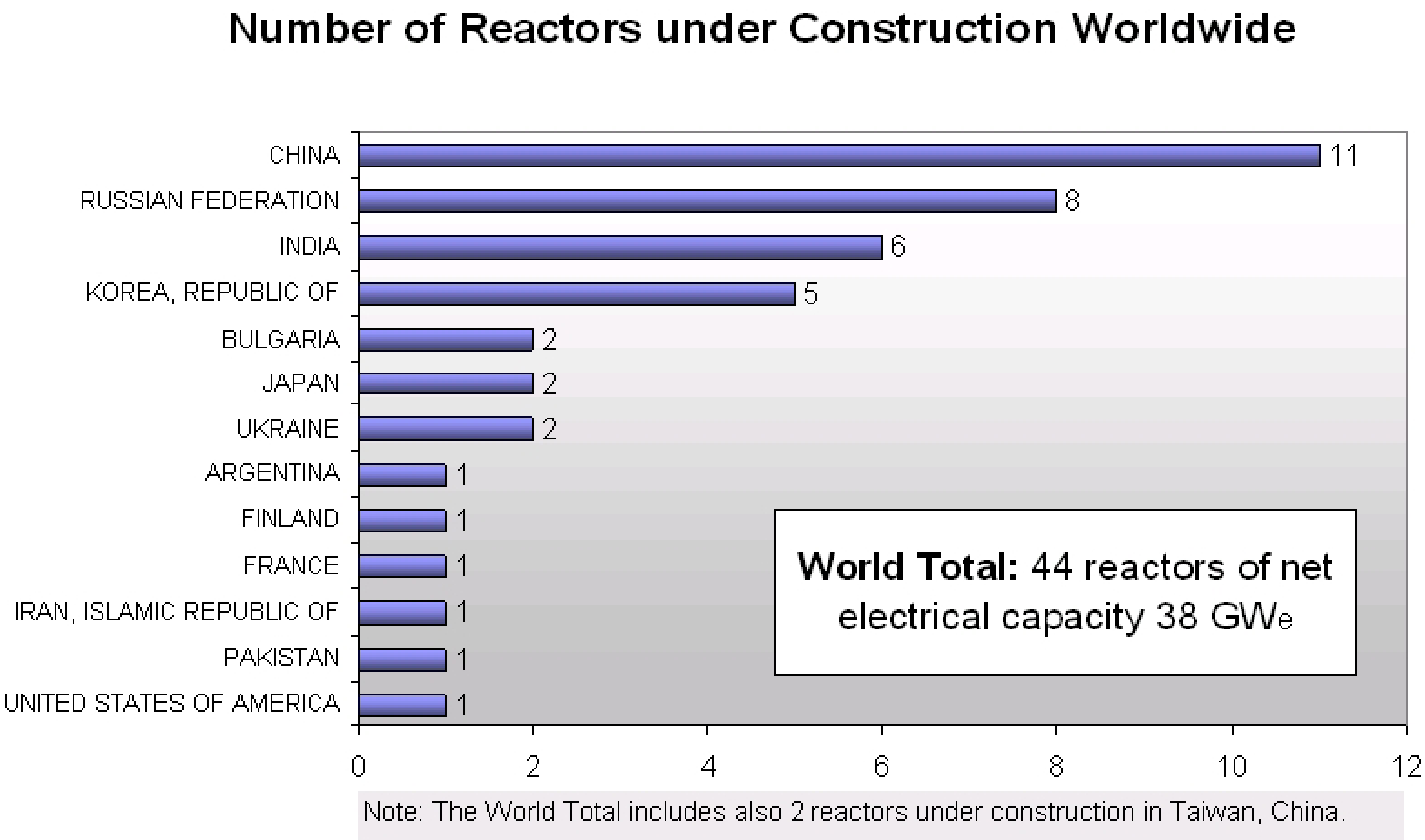
Type	Model	Electric power	Supplier	Country of origin
BWR	ABWR	1400 – 1600 MW	GE/Hitachi, Toshiba/W	USA Japan
	SWR1000	1250 MW	Areva	France
	ESBWR	1550 MW	GE/Hitachi	USA
PWR	EPR	1600 – 1750 MW	Areva	France / Germany
	AP1000	1150 MW	Westinghouse	USA
	APWR	1700 MW	Mitsubishi	Japan



More than 40 New Nuclear Power Plant Builds in Progress and Another Close to 100 are Planned

Nuclear power plants information



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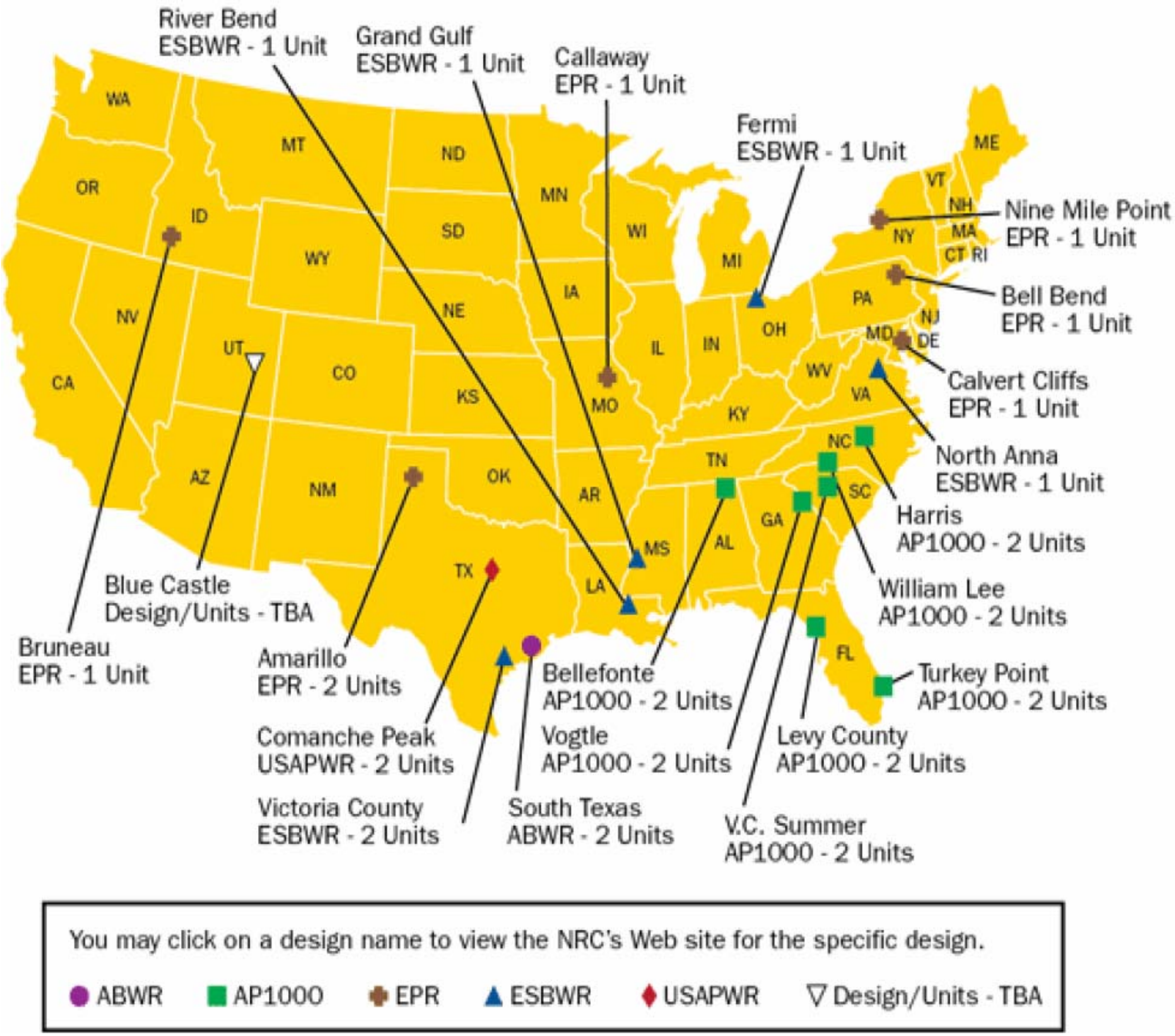
New Plants Planned in the USA



Planned New Builds in the USA

(32 units)

Planning of New Nuclear Power Plants

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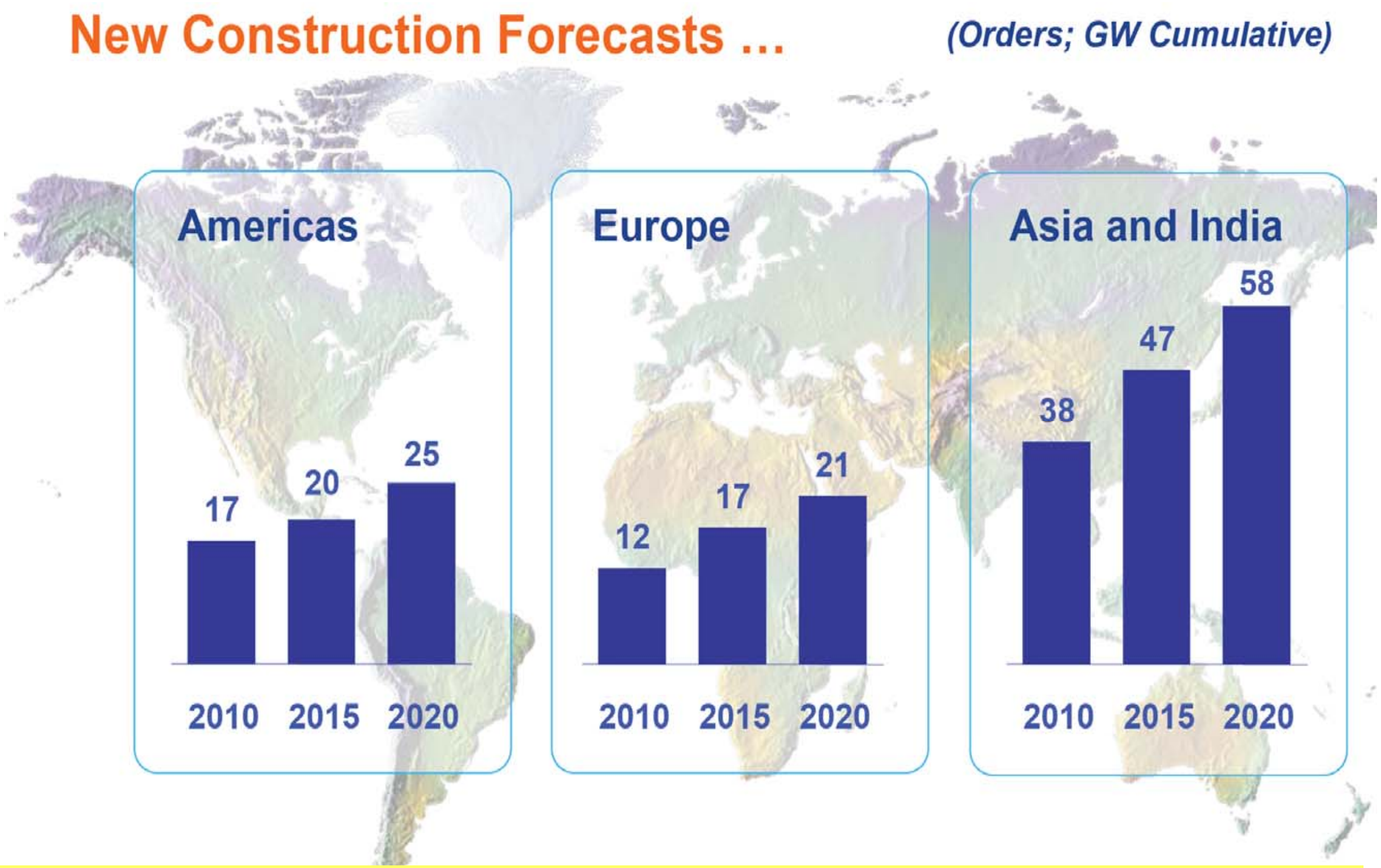

In June 2008, 41 power reactors were under construction in 14 countries

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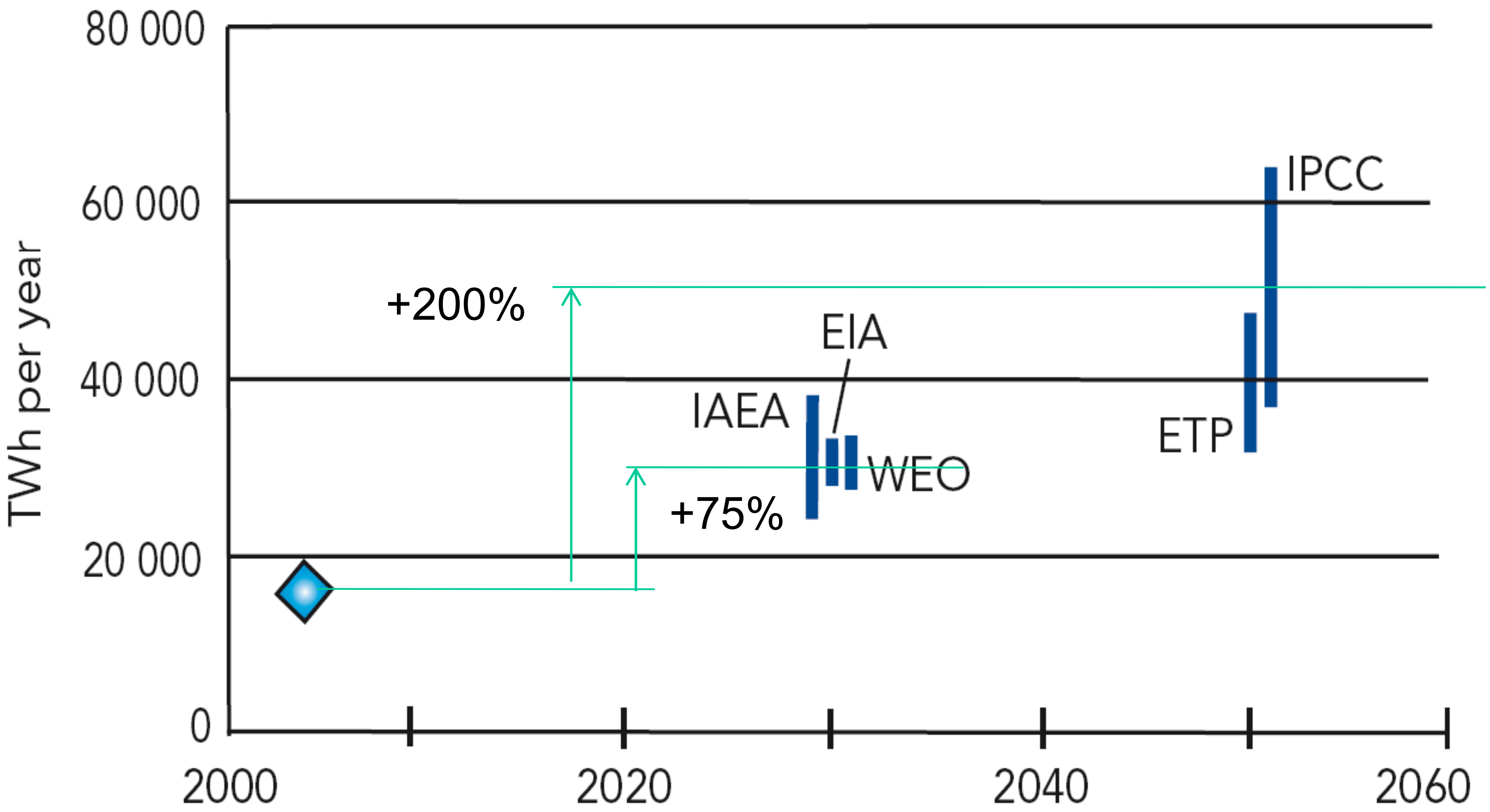
Projected Increase in Electricity Demand Worldwide



Source : OECD/NEA,
"Nuclear Energy Outlook",
NEA No. 6348

EIA = US Department of Energy, Energy Information Administration, 2007
ETP = International Energy Agency, Energy Technology Perspectives, 2006
IAEA = International Atomic Energy Agency, 2005
IPCC = Intergovernmental Panel on Climate Change, 2007
WEO = International Energy Agency, World Energy Outlook, 2007

Ranges of Projected Installed Nuclear Capacity in 2030

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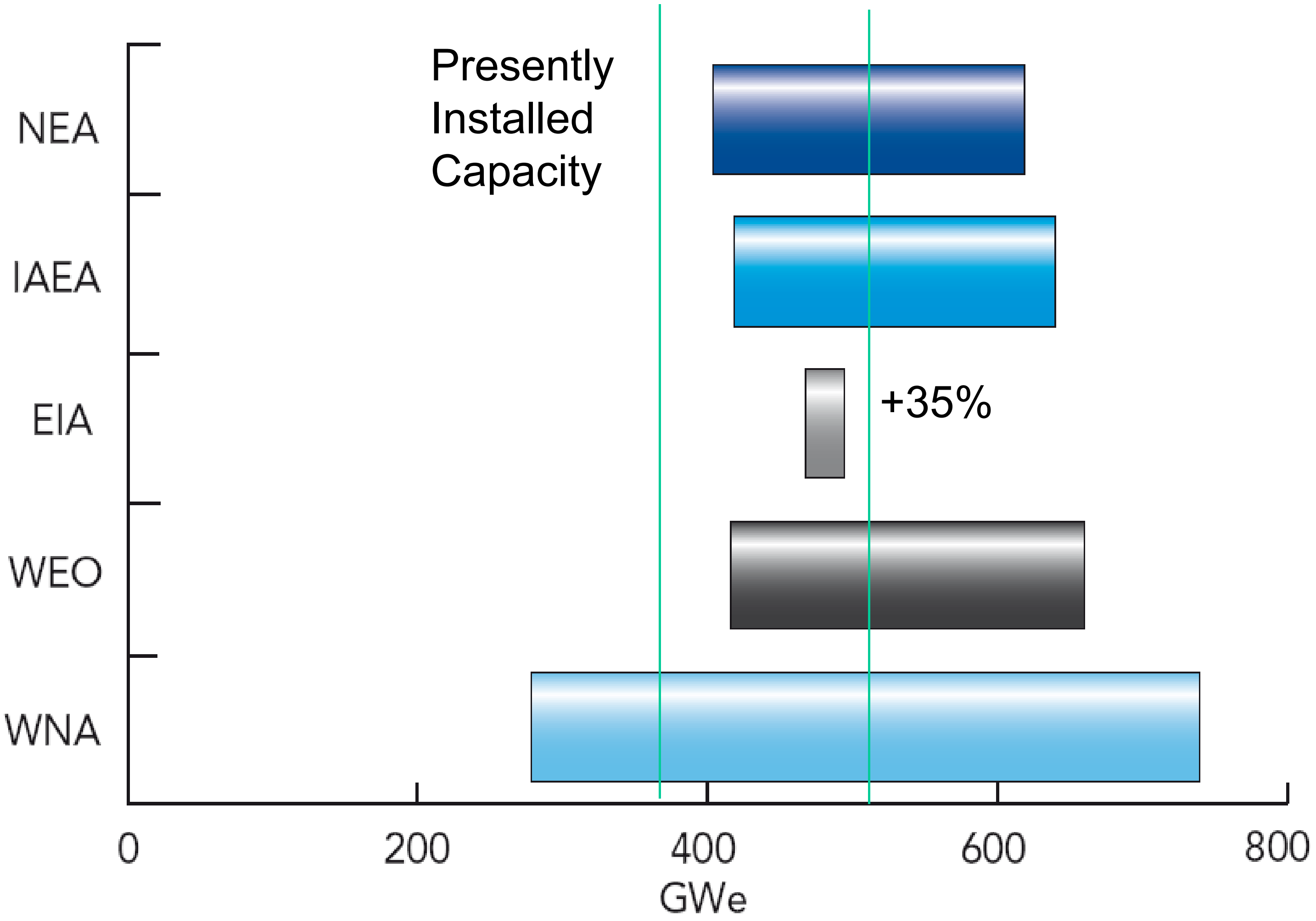

Source : OECD/NEA, "Nuclear Energy Outlook", NEA No. 6348

WNA = World Nuclear Association, 2005

Ranges of Projected Installed Nuclear Capacity in 2050

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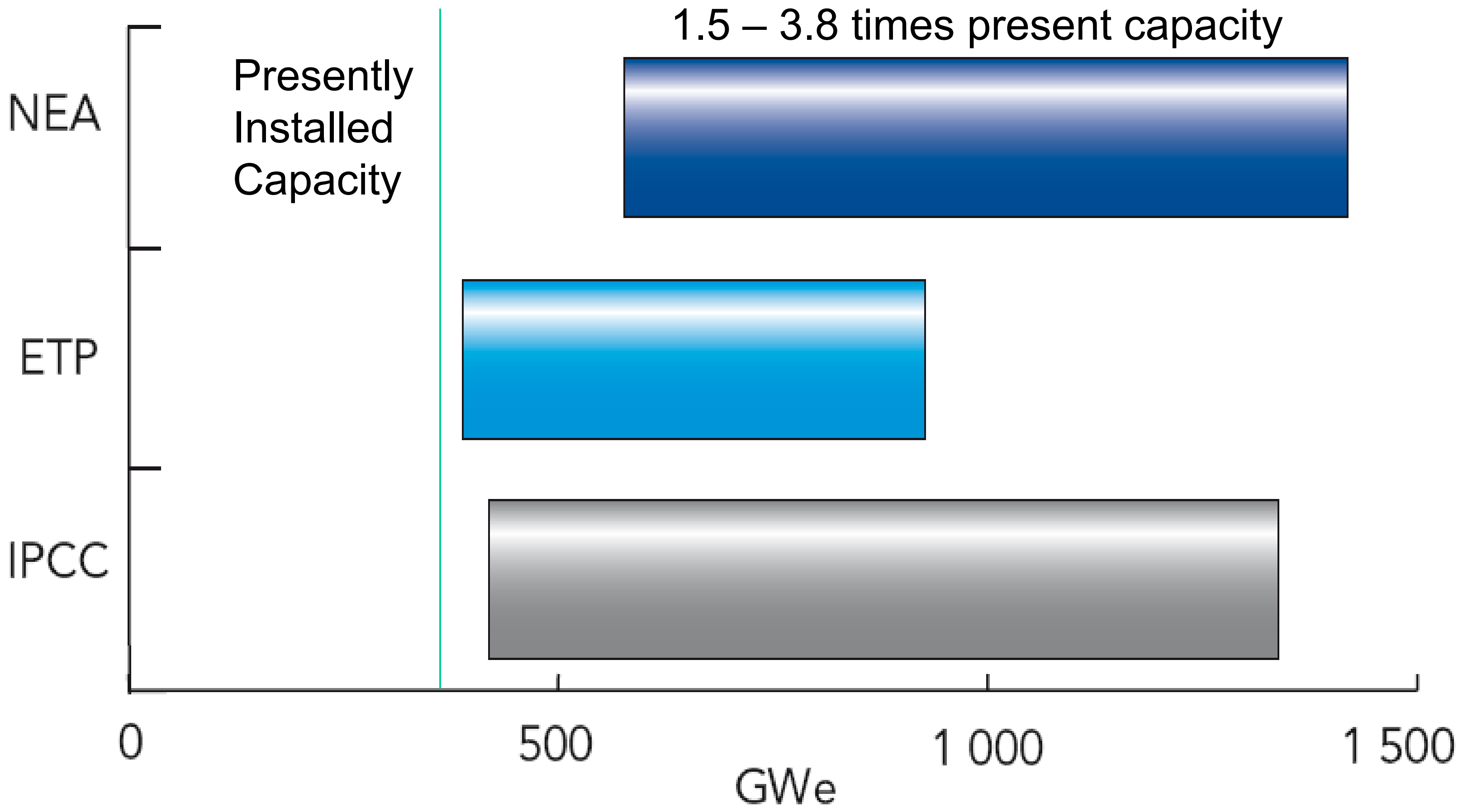

Source : OECD/NEA, ”Nuclear Energy Outlook”, NEA No. 6348

Renaissance for nuclear power?

- Finland: applications for reactor units 6-7-8. France: construction of EPR at Flamanville. England: decision in principle on new NPP units
- Germany, Belgium: Nuclear phase out.
- Holland considers expansion.
- Rapid growth in SE Asia: China +120 GWe, India +50 GWe in 2030.
- Russia: +20 GWe in 2020?
- USA: Applications for COL for up to 32 units. Life extension for existing reactors.
- Italy, Poland consider nuclear option
- Sweden NPP uprates. February 2009: political decision on replacement of existing 10 reactor units when retired.
- Denmark?


Thank you for your attention!